VOLUME 14, NO. 7
JULY 1982

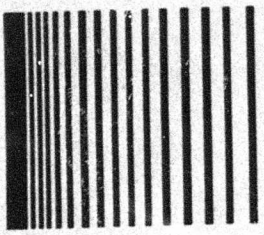
# THE SHOCK AND VIBRATION DIGEST

A PUBLICATION OF
**THE SHOCK AND VIBRATION INFORMATION CENTER**
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C.





OFFICE OF
THE UNDER
SECRETARY
OF DEFENSE
FOR RESEARCH
AND
ENGINEERING



# THE SHOCK AND VIBRATION DIGEST

Volume 14, No. 7
July 1982

## STAFF

**SHOCK AND VIBRATION INFORMATION CENTER**

EDITORIAL ADVISOR: Henry C. Pusey

**VIBRATION INSTITUTE**

TECHNICAL EDITOR: Ronald L. Eshleman

EDITOR: Judith Nagle-Eshleman

RESEARCH EDITOR: Milda Z. Tamulionis

PRODUCTION: Deborah K. Howard
Gwen Wassilak
Vicki Pate

## BOARD OF EDITORS

R. Belsheim
R.L. Bort
J.D.C. Crisp
D.J. Johns
K.E. McKee
C.T. Morrow
W.D. Pilkey
E. Sevin
J.G. Showalter
R.A. Skop
R.H. Volin
H.E. von Gierke

A publication of

THE SHOCK AND VIBRATION INFORMATION CENTER

Code 5804, Naval Research Laboratory
Washington, D.C. 20375

Henry C. Pusey
Director

Rudolph H. Volin

J. Gordon Showalter

Jessica P. Hileman

Elizabeth A. McLaughlin

The Shock and Vibration Digest is a monthly publication of the Shock and Vibration Information Center. The goal of the Digest is to provide efficient transfer of sound, shock, and vibration technology among researchers and practicing engineers. Subjective and objective analyses of the literature are provided along with news and editorial material. News items and articles to be considered for publication should be submitted to:

Dr. R.L. Eshleman
Vibration Institute
Suite 206
101 West 55th Street
Clarendon Hills, Illinois 60514

Copies of articles abstracted are not available from the Shock and Vibration Information Center (except for those generated by SVIC). Inquiries should be directed to library resources, authors, or the original publishers.

This periodical is for sale on subscription at an annual rate of $140.00. For foreign subscribers, there is an additional 25 percent charge for overseas delivery on both regular subscriptions and back issues. Subscriptions are accepted for the calendar year, beginning with the January issue. Back issues are available - Volumes 9 through 12 - for $20.00. Orders may be forwarded at any time to SVIC, Code 5804, Naval Research Laboratory, Washington, D.C. 20375. Issuance of this periodical is approved in accordance with the Department of the Navy Publications and Printing Regulations, NAVEXOS P-35.

# SVIC NOTES

## DISCUSSIONS AT SYMPOSIA

The positive value of discussion periods following the presentation of technical papers is largely unchallenged. For the most part the questions and comments are appropriate and relevant, clearly adding to the value of the information presented. Yet I have noted at times that improper remarks are offered which are, at best, unprofessional and, at worst, downright insulting. I recently read a "tongue-in-cheek" article on discussional language* in a delightful publication. I want to share some of the contents of this article with the readers so that they may establish their own guidelines for participation in discussions.

The article suggests that the discussions of papers have a language of their own, often only understood by the discussant and the author. At other times there is a cryptological component that a few experienced members of the audience can grasp. Discussions can be inefficient, consuming as much as one half of the meeting time. Furthermore, the format of discussional language is repetitive and the discussion of the first paper may well have been just as appropriate for the seventh paper. The article offers discussional linguistics as a unique discipline which serves some useful purposes. For example,

- It allows the discussant to insult the presenting author without the knowledge of the audience.
- It places the discussant's name before the audience to his advantage, but with little justification.

The article lists 21 common phrases used in the discussion of scientific papers with translations in parentheses. The following are samples from this list:

- In our laboratory we have recently considered a similar line of investigation. (My colleague just read your last paper.)
- Although we have reached the same conclusion, we have not performed such elegant studies. (Thirteen years of higher education and training haven't altered our personal prejudice.)
- We always look forward to the author's presentations. (This is the third time I've heard you present this paper.)
- The authors have been bold in attempting to solve this problem. (But they have failed miserably.)
- We hope you will continue to enlighten us at future meetings. (By then you may have accumulated enough data to draw a valid conclusion.)

Certain laws of professional discussion are inviolable and must be mastered.

- Never become emotional, but do try to rattle your opponent.
- Do not be concise.
- Avoid the use of hard data.
- Whenever possible, cite undocumented theory.
- Be politely patronizing, but be sure your opponent appreciates the insult.

The article informs us that a group of experienced discussants recently formed an organization dedicated to the further refinement of their skill. The National Union of Registered Discussants, or NURD, now has representatives in every institution. Beware!! The next person to discuss your paper may be a NURD.

H.C.P.

**Stanton P. Nolan, M.D., "On Discussional Language: A Novice's Guide to Phraseology and Translation with Suggestions for the Moderator," The Journal of Irreproducible Results, Vol. 27, No. 2, 1981.*

# EDITORS RATTLE SPACE

## SPECIALIZED TRAINING TODAY

It is interesting that one of the first items to be cut from the budget of an industrial plant during a downturn of the economy is education and training. It is almost as if training of technical personnel is a discretionary luxury rather than a necessary activity. In a society with such technologically intensive industries -- as most are today and will continue to be -- it is difficult to understand why a high level of technical training is not maintained. Many problems can be avoided or solved with well trained and motivated technical personnel.

In general, it is not possible to hire well trained personnel for specific positions in a plant. Instead, individuals are promoted from within a plant or hired from technical schools, colleges, or universities. These individuals have at least two things in common: all need specialized technical training and in-plant experience with equipment. Plant experience is gained through in-plant training and work on the job. An individual can become skilled in processing, operation of equipment, and evaluation techniques. However, in the plant a person usually does not become skilled in such specialized technical areas as vibration measurement and analysis. It is thus necessary for plants without in-depth technical training programs to use external education and training courses. External training has the benefit of exposing individuals to technical ideas from industries other than their own. For instance, many vibration analysis techniques work as well in the power, paper, and metals industries as they do in petrochemical plants.

Why is training cut so quickly from industrial budgets during slow economic periods? Training is expensive and often seems to be something that can easily be eliminated today and perhaps reinstated in better times tomorrow -- without adverse effects on plant operational efficiency. Unfortunately deterioration of the technical skills of personnel actually increases the possibilities for faulty diagnosis, poor decisions, and expensive repairs. On the other hand, money freely spent on crash programs during good economic times does not lead to a steady well planned, uninterrupted program and adequately trained personnel during bad economic times.



It is well known that external training is very expensive. Travel and subsistence, lost man hours, and training costs are substantial expenses associated with courses. External training would be much more effective if those needing training would communicate with organizations that sponsor courses. Regional planning would reduce travel costs. Efficient training schedules would reduce organizational costs and possibly allow some reduction of fees. Distribution of notes prior to a course and distribution of supplementary material after a course would increase the efficiency of training.

Thus there are ways to maintain continuity of technical training in a cost effective manner and to provide and maintain technical capability necessary for efficient plant operation – in both good and bad economic times.

R.L.E.

# TRANSONIC BLADE FLUTTER: A SURVEY OF NEW DEVELOPMENTS

**M.F. Platzer***

***Abstract.*** ***This paper presents a review of current work in transonic blade flutter research. Aerodynamic analyses for the prediction of attached flow flutter, choke flutter, and stall flutter are described. Also reviewed are unsteady aerodynamic measurement and flutter test programs that have recently been completed or are in progress to investigate transonic blade flutter phenomena.***

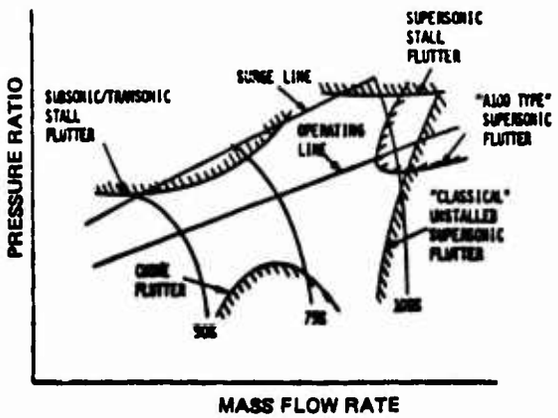
An earlier survey [1] presented a general description of the transonic blade flutter phenomenon and summarized the analytical and experimental investigations devoted to the problem prior to 1978. This paper updates the current status of transonic blade flutter research.

The term transonic flutter is used here to indicate that flow over the outer span of a blade is either transonic or supersonic. Depending on flow conditions, any of four types of flutter can occur:

- transonic choke flutter, when the blade is operating at near-choke conditions
- supersonic unstalled flutter, when the attached flow over the outer span of the blade is either fully supersonic or at least transonic
- supersonic stall flutter, when the outer portion of the blade is operating supersonically but flow is partly or fully separated
- subsonic/transonic stall flutter, when the blade is operating at high subsonic or transonic speeds and is partly or fully separated

Typical flutter boundaries that have been observed on modern compressors are shown in the figure. The choke flutter boundary is encountered during part-speed operation. The blades operate transonically at negative incidence angles and, due to a choked flow, in-passage shocks with possible flow separations are likely to occur.

The supersonic unstalled flutter boundary imposes an important high-speed operating limit. Recent tests have shown that the blade flutter mode during this type of flutter either can be predominantly torsional or consist of a large vibrational deformation of the blade camber line (chordwise bending mode). Still another type of supersonic torsional flutter, designated A-100 flutter, has recently been identified; it occurred only above a threshold level pressure ratio. Two additional flutter boundaries can be encountered during operating near surge: supersonic stall flutter and subsonic/transonic stall flutter.




Types of Fan/Compressor Flutter [27]

## AERODYNAMIC THEORY

As pointed out in the earlier review [1] viscous flow effects are usually ignored at the outset, so that the analysis is based on a suitable approximation of the Euler equations. The fully linearized equations have been widely used in recent years, especially for supersonic oscillating cascades, but more recent work has concentrated on modeling nonlinear flow effects.

*Department of Aeronautics, Naval Postgraduate School, Monterey, California 93940

## FLOW MODELS

Because the analysis of three-dimensional non-steady flow through a transonic multistage machine is prohibitively complex, various simplifying assumptions must be made in order to make the problem mathematically tractable. The most simple and widely used model -- the cascade flow model -- is obtained by unwrapping an annulus of differential radial height from the flow passage of an axial-flow turbomachine. Only one cascade is usually considered because of the complex interactions between neighboring blade rows. As has been pointed out [1] the case of supersonic cascade flow requires further differentiation, depending on the axial through-flow Mach number. This number can be either subsonic (causing propagation of disturbances upstream of the blade leading edges), moderately supersonic (causing interactions only between the reference blade and its adjacent blades), or highly supersonic (causing no interactions between neighboring blades).

Three-dimensional flow models have also been introduced. Examples include flow past a vibrating blade row of finite blade height situated between end plates and flow past an annular blade row with a finite number of vibrating blades rotating at a constant angular velocity in an infinitely long cylindrical duct.

## ANALYSIS OF COMPRESSIBLE FLOW PAST OSCILLATING CASCADES

A subsonic non-steady potential flow analysis [2-4], which accounts for the effects of blade geometry and steady turning, is being developed at the United Technologies Research Center. The formulation is based upon the full nonlinear potential equation, which is linearly perturbed to describe small amplitude blade motions. Hence the problem is reduced to the solution of linear equations with variable coefficients; these in turn must be determined from the steady flow solution.

Finite difference approximations determined from an implicit least-squares method and applicable on arbitrary grids lead to a linear system of algebraic equations that is tri-diagonal and thus permits an efficient non-iterative solution. Special care is required to treat rounded leading edges at angle of attack. Results obtained to date include the effects of cascade geometry, inlet Mach number, and inlet flow angle on the non-steady response of flat plate and NACA 0012 cascades. An extension of this approach to transonic flow is intended in the near future.

Whitehead and Grant [5] attacked this same problem using the finite element method. The assumption of small non-steady perturbations superimposed on the steady high-deflection cascade flow was again made, and the approach again was limited to subsonic inlet and outlet flows or at most with small supersonic shockless bubbles. Computed moment coefficients were in good agreement with experiments available for a turbine cascade.

Several attempts are presently being made to develop transonic oscillating cascade flow solutions that remove some of the limitations imposed by the purely linearized analyses described in the last review [1].

Adamczyk [6] used the transonic small disturbance equation as the governing equation. He was thus able to retain the effect of the steady aerodynamic loading and shock wave motion on the non-steady flow characteristics. The resulting non-steady flow equations can be solved analytically, thus leading to rapid flow computations.

Williams [7] considered small amplitude perturbations superimposed on an arbitrary steady nonuniform flow so that the disturbed flow is isentropic but may be a non-potential flow. Both blade vibration and inflow disturbances are considered. The resulting equations split into acoustic and vortical field equations that are independent of each other. They are solved numerically using the indicial response formulation. Hence the main program output are load time histories -- i.e., aerodynamic transfer functions – that can be used together with a Fourier synthesizer to study flutter and forced response problems.

Kerlick and Nixon [8] also pursued the indicial function approach for the solution of the transonic small disturbance equation together with Nixon's strained coordinate method [29]. This approach permits decoupling of the essentially nonlinear non-steady part of the problem into two linear problems

so that the principle of superposition can be applied. A high-frequency version of the Ballhaus-Goorjian code is being adapted to compute transonic cascade flows by imposing the proper cascade geometry and periodic boundary conditions.

A non-steady aerodynamic analysis has been developed [9] to predict choke flutter; the semi-actuator disk model was used. Because in-passage shocks are likely to occur during this flutter condition, a channel flow model was adopted in which a normal shock was positioned as a function of the pressure perturbations and non-steady airfoil motion. The validity of this model was evaluated by comparison with choke flutter data available from an F-100 core engine that produced reasonable agreement between theoretical predictions and experiments.

Adamson and Messiter [10] have produced detailed analyses of transonic channel flows using asymptotic expansion procedures that permit the study of shock formation and propagation in response to downstream pressure disturbances or to blade motion. Under certain conditions large shock motions occurred. The incorporation of this work into a choke flutter analysis might therefore uncover important additional aspects.

Purely supersonic unsteady cascade analyses have been developed by a number of investigators over the past decade. Most of these approaches are based on the linearized non-steady potential equation and are therefore valid only for very thin blades. The influence of blade thickness and steady loading on supersonic blade flutter characteristics has not yet been resolved, but two papers have recently reported progress on this problem.

Namba [11] developed a model for lightly loaded cascades with weak oblique shocks that can be approximated by Mach lines. The model allows for blade thickness and loading by introducing additional multipole sources fixed at time-mean positions but neglects the effect of deviation of the local convection velocity and local speed of sound from the uniform flow values.

Vogeler [12] developed a method of characteristics solution of the transonic small disturbance equation that accounts for weak shock waves. This work is an extension of earlier work [13] and predicts significant blade thickness effects in some cases.

Halliwell [14] recently evaluated the usefulness of purely linearized supersonic non-steady cascade theory and of a strong normal shock model developed earlier [15] for practical flutter predictions. Halliwell observed that the purely linearized model predicts a much greater range of instability than the normal shock model; he advocates development of an oblique shock model that would reproduce the correct pressure rise-Mach number relationship in the blade passage.

Progress has also recently been made in analyzing supersonic stall flutter of high-speed fans. An analytical model for predicting the onset of supersonic stall bending flutter has been developed [16]. It is based on a modified two-dimensional compressible non-steady actuator disk theory. This model comprises a cascade of airfoils at 85 percent of the blade span; the airfoils are assumed to be unshrouded and to vibrate in their first flexural mode. Shock wave and flow separation effects are accounted for by incorporating the measured quasi-steady rotor total pressure losses and deviation angles.

## EXPERIMENTAL PROGRAMS

Since the last review [1] a number of experimental programs have been continued or initiated to investigate high-speed blade flutter phenomena.

Tests in the Allison supersonic cascade tunnel have been continued. Two cascades of airfoils modeling outboard sections of rotors experiencing supersonic torsional and translation flutter have been investigated; a five-bladed cascade was harmonically oscillated in the proper mode at varying interblade phase angles. Oscillatory pressures were recorded from flush-mounted, high response pressure transducers. Cascade stability plots were obtained over a range of back pressures; it was determined that large amplitude shock motion was not required for torsional instability. The experimental data were correlated with both a low-back pressure and a high-back pressure (normal shock) analysis; a requirement for a moderately loaded cascade analysis was identified. This program was sponsored by NASA-Lewis [17].

Another series of tests was performed in the Allison rectilinear turbine cascade facility. A cascade of five airfoils was used to model the hub section of an advanced design turbine featuring a high subsonic inlet Mach number. Either subsonic or low supersonic exit Mach number was oscillated in the pitch or plunge mode at varying interblade phase angles and frequencies. The oscillatory pressure signals were measured with Kulite pressure transducers and correlated with a state-of-the-art analytical prediction based on a flat-plate cascade [28].

Another NASA-Lewis-sponsored program [18] is being conducted at General Electric. A 32-percent scale rotor of the Quiet Engine Program (QEP) Fan C design is being tested for stall flutter in both the subsonic and supersonic regions. The scaled down fan operates at a design pressure ratio of 1.6. Steady aerodynamic instrumentation was used to measure overall rotor and blade element performance. Non-steady aerodynamic characteristics were determined with blade-mounted sensors, casing-mounted sensors, and traversable dynamic probes. Test results obtained thus far have demonstrated successful duplication of flutter modes and boundaries experienced on the full scale fan C and the acquisition of steady and non-steady aerodynamic data during both steady-state and flutter rotor operating conditions.

At the NASA-Lewis Research Center a linear cascade tunnel is under development [19] to study transonic stall flutter. Flow visualization and dynamic pressure instrumentation are being used to determine transonic flow through an oscillating blade row in order to simulate realistic transonic flutter conditions.

At Modane, France, a high-speed cascade tunnel was put in service by ONERA in 1978. It has been operating at Mach numbers from 0.4 to 1.0 but is designed for supersonic testing. The cascade consists of six blades that are instrumented with pressure transducers [20]. A recently completed stall flutter investigation [21] showed that the non-steady pressures causing stall flutter of thin compressor blades occurred mainly on the forward half of the upper surface.

At the Technical University of Lausanne [22] an annular cascade tunnel capable of testing transonic turbine blades is under development. The Japanese are also interested in the problem of transonic steam turbine blade flutter; a nine-blade cascade has been tested over a range of outlet Mach numbers up to 1.8 [23]. Shock-induced flow oscillations occurred over a limited range of pressure ratios that led to negative aerodynamic pitch damping.

Transonic/subsonic compressor stall flutter has been investigated at Pratt and Whitney Aircraft Company [24]; a modern, shrouded fan stage (TS22 fan) was used. Steady-state structural deformations of the blades were determined by means of blade mounted mirrors. Non-steady deformations during flutter were obtained from mirrors, strain gages, and high-response pressure transducers. Traversing hot film probes were used upstream and downstream of the rotor to detect evidence of flutter in the blade wakes. The major findings were that all 32 blades fluttered at the same frequency but significantly varied in amplitude and interblade phase angle. The measured non-steady pressure distributions indicated that major flutter input occurred close to the blade leading edges. It was also found that the local Mach number had to exceed one for stall flutter to develop and that there was evidence of shock oscillation.

At Massachusetts Institute of Technology (MIT) a method has been developed and demonstrated to measure directly the aerodynamic forcing and aerodynamic damping of a transonic compressor [25]. The MIT transonic compressor -- described by Kerrebrock [26] -- was instrumented with piezoelectric displacement transducers, three accelerometers to measure in-plane motion of the disk, and a leading-edge mounted total pressure transducer.

When operated in rotating stall, the blades were excited at the fundamental frequency of stall cell excitation. The rotor was excited close to the operating point by a controlled two-per-revolution fixed upstream disturbance and then was sharply terminated during the test run. The disturbing and damping forces were determined by an inverse solution of the structural dynamic equations of motion of the blade-disk system; these equations were expressed in individual blade coordinates. The aerodynamic damping of the MIT-rotor was successfully determined; the structural dynamic blade-disk interaction of the rotor was dominated by the in-plane rigid body modes of the disk.

## SUMMARY AND OUTLOOK

It is apparent from the major papers published since the previous review [1] that the dominant aerodynamic model is still the cascade flow model -- i.e., the two-dimensional flow representation. However, considerable effort is being devoted to approaches based on nonlinear governing equations. Hence significant advances in non-steady transonic cascade aerodynamics and in the analysis of steady loading effects on blade flutter can be expected in the next few years.

A number of cascade and rotating rig tests have been completed or are being built to provide a data base for assessing the prediction methods. Nevertheless, flutter phenomena strongly influenced by flow separation, shock-boundary layer interactions, three-dimensional flow effects*, and blade row interactions continue to impose great uncertainties on the predictive capability of current methods. These phenomena will require continued theoretical and experimental efforts.

## REFERENCES


1. Platzer, M.F., "Transonic Blade Flutter: A Survey of New Developments," Shock Vib. Dig., 10 (9), pp 11-20 (Sept 1978).

2. Verdon, J.M. and Caspar, J.R., "Subsonic Flow Past Oscillating Cascade with Finite Mean Flow Deflection," AIAA J., 18 (5), pp 540-548 (May 1980).

3. Caspar, J.R. and Verdon, J.M., "Numerical Treatment of Unsteady Subsonic Flow Past an Oscillating Cascade," AIAA Paper No. 80-1428 (July 1980).

4. Verdon, J.M. and Caspar, J.R., "Development of an Unsteady Aerodynamic Analysis for Finite Deflection Subsonic Cascades," UTRC-Report R80-914777-7 (Dec 1980).

5. Whitehead, D.S. and Grant, R.J., "Force and Moment Coefficients for High-Deflection Cascades," Proc. 2nd Intl. Symp. Aeroelasticity Turbomachines, Lausanne, pp 86-127 (Sept 8-12, 1980).

6. Adamczyk, J., work in progress.

7. Williams, M.H., work in progress under NASA-Lewis grant.

8. Kerlick, D.G. and Nixon, D., "A High-Frequency Transonic Small Disturbance Code for Unsteady Flows in a Cascade," AIAA Paper No. 82-0955 (June 1982).

9. Micklow, J. and Jeffers, J., "Semi-Actuator Disk Theory for Compressor Choke Flutter," NASA-CR-3426.

10. Adamson, T.C. and Messiter, A.F., "Unsteady Transonic Flows in Two-Dimensional Channels with Oscillating Boundaries," Appl. Anal. Inc. Final Report AAI-0587-FT (Oct 1981); also see AIAA J., 16, pp 1240-1247 (1978).

11. Namba, M. and Minami, R., "Effect of Mean Blade Loading on Supersonic Cascade Flutter," Proc. 2nd Intl. Symp. Aeroelasticity Turbomachines, Lausanne, pp 323-332 (Sept 8-12, 1980).

12. Vogeler, K., "A Method of Characteristic Solution for a Finite Oscillating Supersonic Cascade with Thickness Effects," Proc. 2nd Intl. Symp. Aeroelasticity Turbomachines, Lausanne, pp 333-347 (Sept 8-12, 1980).

13. Strada, J.A., Chadwick, W.R., and Platzer, M.F., "Aeroelastic Stability Analysis of Supersonic Cascades," J. Engrg. Power, Trans. ASME, 101, pp 533-541 (Oct 1979).

14. Halliwell, D.G., "Some Aerodynamic Considerations in the Prediction of Unstalled Supersonic Flutter in Transonic Fans," Proc. 2nd Intl. Symp. Aeroelasticity Turbomachines, Lausanne, pp 309-322 (Sept 8-12, 1980).

15. Goldstein, M.E., Braun, W., and Adamczyk, J.J., "Unsteady Flow in a Supersonic Cascade with Strong In-Passage Shocks," J. Fluid Mech., 83, Pt. 3, pp 569-604 (1977).

16. Adamczyk, J., Stevans, W., and Jutras, R., "Supersonic Stall Flutter of High-Speed Fans," ASME Paper No. 81-GT-184.


* ***Very recently Namba [30] developed a lifting surface theory for unsteady three-dimensional flow in rotating subsonic, transonic and supersonic annular cascades which predicts significant three-dimensional effects near sonic blade span stations.***

17. Riffel, R.E. and Rothrock, M.D., "Experimental Determination of Unsteady Blade Element Aerodynamics in Cascades," Torsional Mode Cascade Final Rept. Vol. I, NASA-CR-159831, Translational Mode Final Rept. Vol. II, NASA-CR-165166.

18. Work in progress under NASA-Lewis contract.

19. Boldman, D.R., Buggele, A.E., and Michalson, G.M., "Stall Flutter Experiment in a Transonic Oscillating Linear Cascade," NASA-TM-82655.

20. Szechenyi, E. and Finas, R., "Aeroelastic Testing in a Straight Cascade Wind Tunnel," Proc. 2nd Symp. Aeroelasticity Turbomachines, Lausanne, pp 143-149 (Sept 8-12, 1980).

21. Szechenyi, E. and Girault, J.P., "A Study of Compressor Blade Stall Flutter in a Straight Cascade Wind Tunnel," Proc. 2nd Symp. Aeroelasticity Turbomachines, Lausanne, pp 163-169 (Sept 8-12, 1980).

22. Kirschner, A.M. and Fosco, B., "Control of Vibration in Aeroelastic Cascade Experiments," Proc. 2nd Symp. Aeroelasticity Turbomachines, Lausanne, pp 285-295 (Sept 8-12, 1980).

23. Araki, T., Arinobu, M., Okamoto, Y., and Ohtomo, F., "Self-Excited Flow Oscillation in the Low Pressure Steam Turbine Cascade," Proc. 2nd Symp. Aeroelasticity Turbomachines, Lausanne, pp 171-186 (Sept 8-12, 1980).

24. Stargardter, H., "Subsonic/Transonic Stall Flutter Study," Final Rept., NASA-CR-165256 (June 1979).

25. Crawley, E.F., "Measurements of Aerodynamic Damping in the MIT Transonic Rotor," MIT GTL Rept. No. 157 (Feb 1981).

26. Kerrebrock, J.L., "Flow in a Transonic Compressor Rotor," Transonic Flow Problems in Turbomachinery (T.C. Adamson and M.F. Platzer, Eds.), pp 485-513, Hemisphere Publ. Corp. (1977).

27. Fleeter, S., "Aeroelasticity Research for Turbomachine Applications," AIAA Paper No. 77-437 (1977).

28. Jay, R.L., Rothrock, M.D., Riffel, R.E., and Sinnet, G.T., "Time-Variant Aerodynamics for Torsional Motion of Large-Turning Airfoils," Detroit-Diesel Allison Rept. DDA-EDR-10192 (Jan 1980); report on bending motion to be published soon.

29. Nixon, D., "Notes on the Transonic Indicial Method," AIAA J., 16 (6), pp 613-616 (June 1978).

30. Namba, M. and Ishikawa, A., "Three-Dimensional Aerodynamic Characteristics of Oscillating Supersonic and Transonic Annular Cascades," ASME Paper No. 82-GT-126 (Apr 1982).

# LITERATURE REVIEW: survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

This issue of the DIGEST contains articles about active control technology in aircraft and wind excited behavior of structures.

Dr. D. McLean of Loughborough University of Technology, England has written an article on the developments in active control technology on aircraft. Relaxed static stability, maneuver load control, fatigue reduction, ride control, flutter mode control, and gust load alleviation are described.

Professor D.J. Johns of Loughborough University of Technology, England has written a paper reviewing recent literature on wind-excited behavior of structures. Among the phenomena considered are those due to vortex shedding, galloping, flutter, divergence, and turbulence. Theoretical and experimental (model and full scale) studies are included as are techniques to alleviate wind excited behavior.

# ACTIVE CONTROL TECHNOLOGY IN AIRCRAFT

D. McLean*

*Abstract. This article describes developments in active control technology (ACT) on aircraft. The following functions are described: relaxed static stability (RSS), maneuver load control (MLC), fatigue reduction (FR), ride control (RC), flutter mode control (FMC), and gust load alleviation (GLA).*

Several definitions of active control technology (ACT) have been proposed [1, 2, 3]; for the purpose of this review, the following is used: active control technology is the intentional use on an aircraft of automatic control systems. The systems involve feedback control rather than passive aerodynamic design features and are used to drive a number of specific control surfaces and possibly auxiliary force and moment generators. These controls improve the structural behavior of the aircraft and the dynamic characteristics of its flight.

Aircraft are designed to attain maximum aerodynamic efficiency with the least possible structural weight. It is the purpose of ACT to provide, in conjunction with advanced electronic technology and control theory, the potential to increase both the performance and the operational flexibility of aircraft. Current requirements for the design and operation of aircraft are such that the configuration has been greatly altered from earlier and more familiar designs. Achievement of design requirements has involved the use of thin lifting surfaces, long slender fuselages, low-mass function structures, low load factors, and high stress design levels. Aircraft with such light and flexible structure can develop large amplitude displacements and accelerations as a result of structural deflections. Structural deflections occur as a result of maneuver command or turbulence. Displacements and accelerations can reduce airframe life because of the high stress and load levels to which the airframe is repeatedly subjected. A new class of flight control problems that has emerged [4] requires solution methods different from those used to solve conventional flight control problems. Problems include [5-8] minimizing the loading on the aircraft, either completely or at a few specified locations; accurately controlling the location of the center of gravity of the aircraft over the flight envelope; suppressing flutter; and reducing gust effects. Increasing the damping or stiffness of the structure would diminish performance, reduce the range, or restrict the payload. It is for these reasons that ACT is being keenly pursued.

## ACT CONTROL FUNCTIONS

The most significant improvements in aircraft performance and structural behavior will most likely be achieved by using any or all of six major ACT functions [9-11]. They are relaxed static stability (RSS), maneuver load control (MLC), fatigue reduction (FR), ride control (RC), flutter mode control (FMC), and gust load alleviation (GLA).

Relaxation of the requirements for static stability enhance control response and improve the maneuvering performance [12, 13] while maintaining necessary dynamic stability and handling qualities. If the static stability requirement is relaxed, a smaller empennage (tail assembly) can be used because the empennage is sized to provide only trim requirements. If the empennage is smaller, some saving in overall aircraft weight is possible, and both initial and operational costs of the aircraft are reduced. If static stability is relaxed, ride quality is also affected [14], and an RC function might also be required.

The MLC technique redistributes wing lift during in-flight maneuvers. It is possible to reduce incremental stresses by shifting inboard the center of lift of the wing. The shift is effected by symmetrical

*Department of Transport Technology, Loughborough University of Technology, Leics. LE11 3TU, England

deflection of control surfaces mounted at the proper location on the trailing edge of the wing [15-18]. Such control action is taken in response to load factor commands. The same shift of the center of lift also reduces the bending moment at the wing root. This reduction is an important factor in the fatigue life of the wing [19]. MLC is occasionally referred to as active lift distribution control (ALDC) [20] or as a load increment control system (LICS) [21].

ACT has been used to minimize amplitude and the number of transient bending cycles to which an aircraft structure might be subjected during flight [22-25]. The basis for fatigue reduction is Minor's hypothesis.

The objective of ride control (RC) systems is to improve the smoothness of the ride by reducing vibrations caused by rigid-body and structural motion [26]. Controlled deflections of appropriate control surfaces are used. For bomber aircraft such systems are required to reduce vibrations or accelerations only at crew stations or wherever a vibration-sensitive cargo is being transported. For transport aircraft reduction is required for the entire length of the passenger cabin [27, 28]. In interdiction aircraft during high-speed, low-level strike missions, pilot must be able to track a target; thus accelerations due to turbulence must be prevented [29, 30]. Mission requirements therefore considerably influence the purpose and design of the ride control system [31].

Controlled deflection of auxiliary control surfaces allows damping of flutter modes [32]; an increase can sometimes be achieved in flutter speed and a decrease in structural weight [33]. In fighter and strike aircraft, however, the chief benefit of flutter mode control (FMC) is the possibility of increasing wing-mounted stores [34-36]. Of all ACT functions, FMC is the most sensitive to aircraft configuration, particularly the form and thickness of the wing [37-40].

The air through which an aircraft flies is constantly in motion; consequently, the aerodynamic forces and moments generated by the aircraft fluctuate randomly about their equilibrium values. These changes cause the aircraft to move up or down, to pitch about its center of mass, to roll about the flight line, and to yaw about the heading of the aircraft. Such motions result in accelerations that can be unpleasant to the crew and any passengers. Reduction of these accelerations requires that gust effects be cancelled by other forces [41].

Sensors provide signals to the feedback controller; these in turn cause deflections of control surfaces that generate the aerodynamic forces and moments needed to cancel the acceleration caused by a gust [42]. Gust load alleviation (GLA) is closely allied to RC; both are often used in a single system [43-45]. Moreover, a successful GLA system can contribute substantially to a reduction in structural loads or to the control of flutter modes. Thus, it is possible to find MLC and GLA [46-49] or FMC and GLA [50-52] being employed together.

The benefits expected of ACT functions depend on several aircraft parameters. The only function likely to provide benefits independent of the speed range of the aircraft is ride control [53]. FR, MLC, and GLA are most beneficial for STOL aircraft because of their low wing loading. Improvements in the handling qualities of supersonic transports, which operate over a wide range of dynamic pressure, cannot be obtained by modifying aircraft configuration. Therefore, some type of stability augmentation is required. If RSS is used to obtain drag improvement, a stability augmentation system (SAS) will provide the necessary dynamic stability in addition to the ride qualities.

The elastic characteristics of the large wings of large air transports include low bending frequencies. This kind of design requires both GLA and MLC, in addition to SAS, to provide acceptable handling qualities [54-60]. The forebodies of the long slender fuselages characteristic of supersonic transport and bomber aircraft act as cantilevered beams mounted forward of the stiff structure. The frequencies of the modes associated with side and vertical acceleration are approximately 1Hz [61-69]. Because such frequencies cause discomfort, an RC function is needed. Such a system has been fitted in the B1 for low-level bombing missions: it is called a low altitude ride control (LARC) system. In new transport designs every drag reduction technique, including RSS and high-aspect ratio wings, will be used to improve energy conservation for high-altitude cruise. However, the aircraft will be more difficult

to handle, particularly in clear air turbulence; consequently GLA is required.

Further advantages are expected from the application of ACT to combat aircraft, particularly with respect to maneuvering performance and stall and spin characteristics. A considerable amount of work has been undertaken in the United States and the United Kingdom to evaluate the potential benefits of employing such functions [70-75].

***Gust load alleviation.*** The effects of gust disturbances on aircraft have concerned designers since the earliest days of aviation. The earliest technical paper was in 1915 by Hunsaker and Wilson [76]. A patent was granted in 1914 to Sprater [77] for a "stabilizing device to counteract the disturbance (gust) and prevent it from having an injurious effect on the stability of the machine." Suitable mathematical representations of turbulence were developed by Von Karman [78] and Taylor [79]. A French proposal for a gust alleviation system [80] appeared in 1938 but was flight tested in the U.S.A. only in 1954.

In 1949 in U.K. the Bristol Brabazon was fitted with a GLA system that was also intended to achieve some MLC. Because this system had been fitted, the wing structure of the prototype aircraft was 20% weaker than the figure required to meet specified gust levels in the absence of a GLA system. The Brabazon system used symmetrical aileron deflection in response to signals from a gust vane mounted on the nose of the aircraft. The system was never flight tested, however, and the project was abandoned in 1953 [81].

In 1950 Douglas Aircraft Corporation carried out flight tests on a C-47 fitted with auxiliary flaps for gust alleviation [82]. A series of tests were carried out in 1952 in the U.S.A. using a C-54 [83, 84]. The RAE conducted tests in the U.K. using an AVRO Lancaster [85, 86]. All these systems depended on a gust vane to detect entry into a gust field. The vane sensed either changes of pressure or a change of direction of the wind. These systems were unsatisfactory because the gust had components normal to the plane of symmetry of the aircraft that were undetected. In addition, such secondary effects as downwash acting on the tail; changes in flight condition; and the time delay between the wing and tail encountering the gust were not explicitly considered.

The gust vane systems tried in effect to provide control correction in advance of an actual gust; essentially they were feed-forward or open-loop GLA systems. As a result control systems could not be designed to provide the necessary speed of response or be made insensitive enough to the secondary effects. Recent French and German studies have developed this approach [87-89]. One patent [41] provided the feedback method that has been followed by most research workers. A useful bibliography up to that epochal technical development is available [90].

Of particular concern has been the use of GLA, by means of direct lift or direct side force control, to ameliorate difficult landing situations [91-94]. The effects of gust response and alleviation methods for small general aviation aircraft have been discussed in recent American work [95, 96]. The application of GLA to helicopters and tilt-rotor aircraft is being keenly studied [97-102].

Only Houbolt and Eichenbaum [103-105] have dealt with GLA in three-dimensional gusts. But a number of investigations have been carried out with respect to improving gust load analysis techniques [106-110]. Analytical methods chiefly involve the use of power spectral density functions [111-137]. Several recent studies have involved improving the mathematical representation of atmospheric turbulence [114-117].

Nonlinear gust alleviation effects have been studied [118, 119]. Nonstationary turbulence has been described [119]. Passive gust alleviation has been discussed as a technique in conjunction with flutter suppression [120].

***Maneuver load control.*** Much literature has been concerned with the dynamic representation of the flexibility effects that occur as a result of aeroelasticity [121-131]. This literature also devotes considerable attention to structural loads criteria By means of the modal truncation method developed in earlier papers suitable mathematical models of large flexible aircraft have been used to damp the elastic modes and thereby provide maneuver load control [132-147].

Many systems involve other ACT modes such as GLA or flutter suppression. A special study has been reported on the flexibility of the airfoil as a result of control activity [148]. An investigation of the effects of an MLC system on the dynamic performance of a variable sweepback aircraft has been reported [149].

***Flutter mode control.*** Flutter instability impedes achievement of the best performance from an aircraft. Considerable effort has been devoted to analyzing flutter behavior and instability [150-156]. Principal causes of concern relate to wing flutter caused by carrying underwing stores on pylons and the effects of their release [157-161]. Much effort is being devoted, principally in the U.S.A. and W. Germany, to designing ACT systems to suppress flutter at operational speeds [162-165].

***Ride control systems.*** Ride control is achieved by GLA, MLC, or FMC functions. There is, however, uncertainty about what constitutes satisfactory ride quality. Various writers [166-170] have attempted to present satisfactory ride quality criteria and to describe ways for analyzing them, or achieving them by an RCS.

One Chinese paper is concerned with shaking in flight [171]. Some work has been undertaken to assess the influence of the pilot, represented by a mathematical model, on ride quality [172-173]. An assessment of how ride quality is affected by passage through extreme turbulence in the form of thunderstorms has been presented [174].

## SUMMARY

The developments in active control technology are progressing rapidly in each of the modes described earlier with the possible exception of fatigue reduction. It is generally expected, however, that extended airframe life will be achieved by GLA, RCS, or MLC functions. Both MLC and RSS are candidates for application to future military and commercial transport aircraft because of rising fuel costs and its decreased availability.

## REFERENCES


1. Ostgaard, M. and Swortzel, F.R., "CCVs: Active Control Technology Creating New Military Aircraft Design Potential," Astronaut. & Aeronaut., 15 (2), pp 42-57 (1977).

2. Roughton, D.J., "Problems Concerning ACT," Proc. Inst. M.C. Colloq. Math. Modelling for ACT, London (1976).

3. Wanner, J.C., "Le Concept CCV," ONERA TP-1975-54, France (1975).

4. Gill, F.R., "On the Design and Evaluation of Flight Control Systems," RAE TM Av. 133 (1973).

5. Gill, F.R., "Control Configured Vehicles," RAE TM Av. 148 (1977).

6. Hepler, A.K. et al, "Applicability of the Control Configured Design Approach to Advanced Earth Orbital Transportation Systems," NASA CR-2723 (1978).

7. Roskam, J., Barber, M.R., and Loschke, P.C., "Separate Surfaces for Automatic Flight Controls," SAE Paper 730304 (1973).

8. Hoffman, L.G. and Clement, W.F., "Vehicle Design Considerations for Active Control Application to Subsonic Transport Aircraft," NASA CR-2408 (1974).

9. Newmann, K.R., "An Introduction and Survey of the U.S. Commitment to Active Control Technology," ARC 36004 (LD. 484), London (1975).

10. O'Connor, W., "Evaluation of Advanced Air Vehicle Designs in the USAF," SAE Paper 730945 (1973).

11. Watson, J.H., "Control Requirements for Control Configured Vehicles," AIAA Proc. 2nd Flight Mech. Conf., Palo Alto, CA (1972).

12. Stengel, R.F. and Berry, P.W., "Stability and Control of Maneuvering High-Performance Aircraft," NASA CR-2788 (1977).

13. Krag, B., "Calculation of Dynamic Response of CCV-Type Aircraft," Ph.D. Thesis, Univ. Brunswick, W. Germany (1976).

14. Roberts, P.A. et al, "Effects of Control Laws and Relaxed Static Stability on Vertical Ride Quality of Flexible Aircraft," NASA CR-143843 (1977).

15. Abel, I. and Sandford, M.C., "Status of Two Studies on the Active Control of Aeroelastic Response," NASA TMX2909 (1974).

16. Andrew, G.M. and Johnson, J.M., "Automatic Control of Aeroelastic Modes," IAS Paper 62-86 (1962).

17. Flannigan, J.B. and Elliott, T.R., "Mechanization of Active Control Systems," AGARD 40th Mtg. Struc. Matl. Panel (1975).

18. Lorenzetti, R.C., Nelson, G.L., and Johnson, R.W., "Computerised Design of Optimal DLC," J. Aircraft, 6 (2), pp 137-143 (1969).

19. Hood, R.V., "Active Controls Changing the Rules of Structural Deisgn," Astronaut. & Aeronaut., 10 (8), pp 50-54 (1972).

20. O'Connell, R.F., "Design, Development and Implementation of an Active Control System for Load Alleviation for a Commercial Transport Airplane," AGARD - R-683, Paris (1980).

21. Van Dierendonck, A.J., Stone, C.R., and Ward, M.D., "Application of Practical Optimal Control Theory to the C-5a Load Improvement Control System (LICS)," AFFDL-TR-73-122 (1973).

22. Roth, G.J., "Development of Flight-by-Flight Fatigue Test Data from Statistical Distributions of Aircraft Stress Data," Vols. I & II, Res. Inst. Rept., Univ. Dayton, Ohio (1975).

23. Buch, A., "Effect of Aircraft Loading Program Modifications on Fatigue Life and Damage Cumulation; Part I," Rept. No. TAE-334-Pt. 1, Technion, Israel Inst. Tech., Haifa (1978).

24. Dejonge, J.B., "Application of Active Controls for the Reduction of Fatigue Loads," NLR-TR-75163-U, Natl. Aerospace Lab., Amsterdam (1975).

25. Stockdale, C.R. and Poyneer, R.D., "Control Configured Vehicle-Ride Control System," AFFDL-TR-73-83 (1973).

26. Richards, L.G., Kuhlthau, A.R., and Jacobson, I.P., "Passenger Ride Quality Determined from Commercial Airline Flights," NASA TM-X-3295, pp 409-436 (1925).

27. Gordon, C.K. and Dodson, R.O., "STOL Ride Quality Feasibility Study Technical Report," NASA CR-2276 (1973).

28. Erkelens, L.J.J. and Schuring, J., "Investigation of a Passenger Ride Comfort Improvement System with Limited Control Surface Actuator Performance for a Flexible Aircraft," NLR-TR-75140-U, Natl. Aerospace Lab., Amsterdam (1975).

29. Fry, D.R. and Winter, J.S., "The Design of Aircraft Automatic Ride-Smoothing Systems Using Direct Lift Control," RAE TR-79045 (1979).

30. Powers, B.G., "Analytical Study of Ride Smoothing Benefits of Control System Configurations Optimised for Pilot Handling Qualities," NASA TP-1148 (1978).

31. Powers, B.G., "Active Control Systems for Load Alleviation, Flutter Suppression, and Ride Control," AGARD AG-175, France (1974).

32. Theissen, J.G. and Robinette, W.C., "Servo Control of Flutter," Proc. AIAA Specialists' Conf. Struc., Dynam., and Aeroelastics, pp 228-239, New Orlenas (1969).

33. Done, G.T.S., "The Effect of Linear Damping on Flutter Speed," ARC R & M 3396 (1965).

34. Perisho, C.H., Triplett, W.E., and Myktow, W.J., "Design Considerations for an Active Suppression System for Fighter Wing/Store Flutter," AGARD 40th Mtg. Struc. Matl. Panel (1975).

35. Sensburg, O., Hoenlinger, H., and Moll, T., "Active Flutter Suppression on an F-4 Air-

craft, with External Stores, Using Already-Existing Control Surfaces," MBB-FE-17/S/Pub/24, Messerschmitt-Boelkow-Blohm Gmbh, Munich (1980).

36. Hoenlinger, H., Sensburg, O., Kuehn, M., and Goedal, H., "Active Control of an Explosive Wing-Store Flutter Case," MBB-FE-17/S/Pub/25, MBB Gmbh, Munich (1980).

37. Nissim, E., "Flutter Suppression Using Active Controls Based on the Concept of Aerodynamic Energy," NASA TN D-6195 (1971).

38. Nissim, E., "Flutter Suppression and Gust Alleviation Using Active Control," NASA-CR-138658 (1974).

39. Nissim, E., "Recent Advances in Aerodynamic Energy Concept for Flutter Suppression and Gust Alleviation Using Active Control," NASA TN.D-8519 (1977).

40. Nissim, E., "Active Controls for Flutter Suppression and Gust Alleviation in Supersonic Aircraft," NASA CR-163934 (1980).

41. Attwood, J.L., Cannon, R.H., Johnson, J.M., and Andrew, G.M., "Gust Alleviation System," US Patent 2,985,409 (May 23, 1961).

42. Davis, H.M. and Swaim, R.L., "Controlling Dynamic Response in Rough Air," AIAA Paper 66-997 (1966).

43. Stewart, E.C., "Discussion of an Aeromechanical Gust Alleviation System to Improve Ride Comfort of Small Airplanes," SAE Paper 750544 (1975).

44. Molner, E.R., "Using Vertical Gust Alleviation to Improve the Target Tracking Capability of the Control Configured YF-16," M.S. Thesis GGC/EE/79-5, USAF Inst. Tech., Wright-Patterson AFB, Ohio (1979).

45. Johnston, D.E. and Klein, R.H., "Manual and Automatic Flight Control during Severe Turbulence Presentation," SAE Paper 740890 (1974).

46. Johannes, R.P. and Burris, P.M., "Flight Controls Damp Big Aircraft Bending -- Smoother Rise Control Results," Control Engr., 14 (g), pp 81-85 (1967).

47. Wykes, J.H., "Structural Dynamic Stability Augmentation and Gust Alleviation of Flexible Aircraft," AIAA Paper 68-1067 (1968).

48. Burris, P.M. and Bender, M.A., "Aircraft Load Alleviation and Mode Stabilization (LAMS) - B-52 System Analysis," Dayton, Ohio (1969).

49. Broadbent, E.G., Zbrozek, J.K., and Huntley, E., "A Study of Dynamic Aeroelastic Effects on the Stability, Control and Gust Response of a Slender Delta Aircraft," ARC R & M 3690 (1971).

50. Andrew, G.M., Johnson, J.M., and Garner, F.H., "Gust Alleviation and Rigidity Augmentor for Supersonic Airplanes," IAS Paper 62-1 (1962).

51. Wiggins, D.A., "Hydraulic Controls for Active Flutter Suppression and Load Alleviation," AGARD 40th Mtg. Struc. Matl. Panel (1975).

52. Wiggins, D.A., "Active Control Systems for Load Alleviation, Flutter Suppression, and Ride Control," AGARD AG-175, France (1974).

53. Wiggins, D.A., "Impact of Active Control Technology on Airplane Design," AGARD CP-157 (1975).

54. Edinger, L.D., "Design of Elastic Mode Suppression Systems for Ride Quality Improvement and Application to an SST," AIAA Paper 67-571 (1967).

55. Holloway, R.B., Burris, P.M., and Johannes, R.P., "Aircraft Performance Benefits from Modern Control Systems Technology," J. Aircraft, 7 (6), pp 550-553 (1970).

56. Holloway, R.B., Thomson, G.D., and Rohling, W.J., "Prospects for Low Wing - Loading STOL Transport with Ride Smoothing," AIAA Paper 72-64 (1972).

57. Hoblit, F.M., "Effect of Yaw Damper on Lateral Gust Loads in Design of the L-1011

Transport (TRISTAR)," AGARD 37th Mtg. Struc. Matl. Panel (1973).

58. Oehman, W.J., "Analytical Study of the Performance of a Gust Alleviation System for a STOL Airplane," NASA TN-D-7201 (1973).

59. Dell, R.F., "A Preliminary Investigation into the Stability and Control Aspects of Control Configured Subsonic Transport Aircraft," Aero/S & C/163 British Aerospace, Weybridge (1974).

60. Lange, R.H. et al., "Application of Active Controls Technology to the NASA Jetstar Airplane," NASA CR-2561 (1975).

61. Smith, R.E. and Lum, E.L.S., "Linear Optimal Control Theory and Angular Acceleration Sensing Applied to Active Structural Bending Control on the XB-70," AFFDL TR-66-68 (1966).

62. Dempster, J.B. and Roger, K.L., "Evaluation of B-52 Structural Response to Random Turbulence with Stability Augmentation System," J. Aircraft, 6 (4), pp 507-513 (1967).

63. Burris, P.M., Dempster, J.B., and Johannes, R.P., "Flight Testing Structural Performance of the LAMS Flight Control System," AIAA Paper 68-244 (1968).

64. Dempster, J.B. and Arnold, J.I., "Flight Test Evaluation of an Advanced SAS for B-52 Aircraft," J. Aircraft, 6 (4), pp 343-348 (1969).

65. Johnson, W.A. and Weir, D.H., "Pilot's Response to SAS Failure and Implications for Design," J. Aircraft, 6 (6), pp 504-509 (1969).

66. Harrington, C.A.I., "Design of a Control System to Stabilize the Aft Fuselage of a B-52 in the Presence of a Random Wind Gust," M.S. Thesis GE/EE/74-M-5, USAF Inst. Tech., Wright-Patterson AFB, Dayton, Ohio (1974).

67. Adams, R.M., "Design of a Modal Controller for the B-52 Control Configured Vehicle," M.S. Thesis, USAF Inst. Tech., Wright-Patterson AFB, Dayton, Ohio (1975).

68. Wykes, J.H., Nardi, L.V., and Mori, A.S., "XB-70 Structural Mode Control System," NASA CR-1577 (1976).

69. Harvey, C.A. and Pope, R.E., "Study of Synthesis Technique for Insensitive Aircraft Control System," NASA CR-2803 (1977).

70. Gill, F.R. and Robinson, P., "Preliminary Studies of the Use of DLC in AFCS," RAE RM Av.108 (1972).

71. Fry, D.E. and Watts, M.R., "Revised Control Laws for Hunter Lateral Manoeuvre Demand Systems," RAE TM Av 145 (1973).

72. Bennett, D.H., "F-4 CCV Flight Tests of Advanced Technology," SAE Paper 740861 (1974).

73. Kreisse meier, G., "Control System Design Using Vector Valued Performance Criteria with Application to the Control Rate Reduction in Parameter Insensitive Control Systems," ESA-TT-512, European Space Agency, Paris (1978).

74. Nguyen, L.T. et al., "Simulator Study of Stall/Post Stall Characteristics of a Fighter Airplane with Relaxed Longitudinal Static Stability," NASA TP-1538 (1979).

75. Nguyen, L.T., Gilbert, W.P., and Osburn, M.E., "Control-System Techniques for Improved Departure/Spin Resistance for Fighter Aircraft," NASA TP-1689 (1980).

76. Hunsaker, J.C. and Wilson, E.B., "Report of Behaviour of Aeroplanes in Gust Turbulence," NACA TM - 1 (MIT) (1915).

77. Sprater, A., "Stabilizing Device for Flying Machines," US Patent 1,119,324 (1914).

78. Von Karman, T., "Fundamentals of the Statistical Theory of Turbulence," J. Aero. Sci., 4 (4), pp 131-139 (1937).

79. Taylor, G.I., "Statistical Theory of Turbulences," J. Aero. Sci., 4 (8), pp 311-315 (1937).

80. Hirsch, R., "Etudes et essais d'un absorbeur des rafales," D.O.C. Aero, 42, pp 13-28, USA (1957).

81. Harper, N.F., "Effect of Active Control Systems on Structural Design Criteria," AGARD 37th Mtg. Struc. Matl. Panel (1973).

82. Hawk, J., Connor, R.J., and Levy, C., "Dynamic Analysis of the C-47 Gust Load Alleviation System," SM-14456, Douglas Aircraft, Santa Monica, CA (1952).

83. Kraft, C.C., "Initial Results of a Flight Investigation of a Gust Alleviation System," NASA TM-3612 (1956).

84. Hunter, P.A. and Kraft, C.C., "A Flight Investigation of an Automatic Gust Alleviation System in a Transport Aircraft," NASA TN D-532 (1961).

85. Zbrozek, J.K., Smith, W., and White, D., "Preliminary Investigation of a Gust Alleviation System on a Lancaster Aircraft," ARC R & M 2972 (1957).

86. Zbrozek, J.K., "Theoretical Analysis of a Gust Alleviator Used on a Lancaster Aircraft and Comparison with Experiment," RAE TN Aero 2645 (1961).

87. Coupry, G., "Pilotage Automatique d'un Avion Volant en Atmosphere Turbulente," AGARD, Paris (1974).

88. Cocquerez, J.L. and Verbrugge, R.A., "Initial Study of the Response of an Aircraft to Lateral Gusts," AAAF-NT-79-03, Universite des Sciences et Techniques, Lille, France (1978).

89. Buchstaller, M. et al., "Open Loop Gust Alleviation," BMFT-FB-W-79-10, Dornier Systems Gmbh, Friedrichshafen, W. Germany (1979).

90. Bryce, B.A., "Annotated Bibliography of Literature Concerning Gust Alleviation Techniques, Low Altitude Atmospheric Turbulence, and Related Topics," EM 1168-104, N. American Aviation (Autonetics Div.), Anaheim, CA (1963).

91. Brainerd, C.H. and Kohlman, D.L., "A Simulator Evaluation of the Use of Spoilers on a Light Aircraft," NASA-CR-2121 (1972).

92. Boothe, E.M. and Ladder, H.J., "Direct Side Force Control (DSFC) for STOL Crosswind Landings," CALSPAN Rept. No. AD-5148-F-1 (1973).

93. Porter, M.B., "The Effects of Stability Augmentation on the Gust Response of a STOL Aircraft during a Curved Manual Approach," AFFDL-TR-75-63 (1975).

94. Schlueter, H.G. and Bender, K., "A Contribution to the Increase of Aircraft Guidance Precision under Wind Disturbance Conditions by Using Direct Digital Control," ESA-TT-506, European Space Agency, Paris (1978).

95. Miller, N. and Petrakis, J.P., "Responses of Small Rigid Aircraft to Discrete and Continuous Gust Analysis - Phase I," FAA Rept. No. NA-74-44 (1975).

96. Williamson, G.G., "Gust Response Analysis for Ten General Aviation Aircraft Using a Two Degree-of-Freedom Power Spectral Technique," ARAP-344, Princeton (1978).

97. Amos, A.K. and Alexander, H.P., "Simulation Study of Gust Alleviation in a Tilt Rotor Aircraft," Vol. 1, NASA CR-152050; Vol. 2, NASA CR-152051 (1977).

98. Yasue, M., "Gust Response and Its Alleviation for a Hingeless Helicopter Rotor in Cruising Flight," ASRL TR-189-1, M.I.T. (1978).

99. Dahl, H. and Weger, D., "Investigation of Oscillatory and Flight Behaviour of Rotor Systems in Relation to Atmospheric Turbulence," BMVG-FBWT-79-5, MBB Gmbh, Munich (1979).

100. Johnson, W., "A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics; Pt. 1: Analysis Development," NASA A-8100 (1980).

101. McKillip, R.M., "The Design, Testing and Evaluation of the MIT Individual Blade Control System as Applied to Gust Alleviation for Helicopters," NASA CR-152352 (1980).

102. Taylor, R.B., Zwicke, P.E., Gold, P., and Miao, W., "Analytical Design and Evaluation of an Active Control System for Helicopter Vibration Reduction and Gust Response Alleviation," NASA CR-152377 (1980).

103. Eichenbaum, F.D., "Response of Aircraft to 3-Dimensional Random Turbulence," Lockheed-Georgia Co., Marietta (1972).

104. Houbolt, J.C., "On the Response of Airplanes in a 3-Dimensional Gust Field," ARAP-161, Princeton (1972).

105. Houbolt, J.C. and Williamson, G., "A Direct Time History Study of the Response of an Airplane to Non-Stationary Turbulence," ARAP-230, Princeton (1975).

106. Foss, K.A., "Effects of Structural Flexibility on Gust Loading of Aircraft; Pt. I," ASRL, MIT 91955.

107. George, D., Smedfield, J.B., and Schiro, G.R., "An Engineering Evaluation of Airplane Gust Loads Analysis Methods; Vol. I: Theoretical Developments," ADR06-14-63-1, Grumman Aircraft, Bethpage, NY (1963).

108. Buxbaum, O. and Zaschel, J.M., "Comparison of Several Models Describing the Gust Loads on Aircraft Structures," LBF-TB-130/76, Laboratorium f. Betriebsfestigkeit, Darmstadt (1976).

109. Kroll, R.I. and Miller, R.D., "Comparisons of Several Aerodynamic Methods for Application to Dynamic Loads Analyses," NASA CR-137720 (1976).

110. Taylor, J., "Mathematical Model for the Separation of Gust and Manoeuvre Loads of Civil Aircraft," FB-141, Laboratorium f. Betriebsfestigkeit, Darmstadt (1979).

111. Vandervaart, J.C., "The Calculation of the R.M.S. Values of an Aircraft's Normal Acceleration due to Gaussian Random Atmospheric Turbulence," VTH-213, Technische Hogeschool, Delft (1976).

112. Sherman, D.J., "The Effect of Spanwise Gust Variations on the Transfer Function of an Aircraft Model with One Degree of Freedom," ARL/STRUC Note 431, Aero. Res. Labs., Melbourne, Australia (1976).

113. Turner, E.W., "An Exposition on Aircarft Response to Atmospheric Turbulence Using p.s.d. Analysis Technique," AFFDL-TR-76-162 (1977).

114. Jones, J.G., "Similarity Theory of Gust Loads on Aircraft Development of Discrete Gust Theory and Introduction of Empirical Functions," RAE TR 69171 (1969).

115. Kaynes, I.W., "Aircraft Centre of Gravity Response to Two-Dimensional Spectra of Turbulence," RAE TR 69271 (1969).

116. Noback, R., "Comparison between the Statistical Discrete Gust Method and the PSD Method," NLR Tr-75158-U, Natl. Aerospace Lab., Amsterdam (1975).

117. Noback, R., "Equations for the Response of an Airplane to Non-Stationary Atmospheric Turbulence Patches," NLR-TR-76056-U, Natl. Aerospace Lab., Amsterdam (1976).

118. Sidwell, K., "A Method for the Analysis of Non-Linearities in Aircraft Dynamic Response to Atmospheric Turbulence," NASA TN-D-D8265 (1976).

119. Noback, R., "A Non-Stationary Model for Atmospheric Turbulence Patches for the Prediction of Aircraft Design Loads," NLR-TR-76131-U, Natl. Aerospace Lab., Amsterdam (1976).

120. Karpel, M., "Design for Active and Passive Flutter Suppression and Gust Alleviation," Ph.D. Thesis, Stamford Univ. (1980).

121. Broadbent, E.G., The Elementary Theory of Aeroelasticity, Aircraft Engrg. Monograph, Bunhill Publ., London (1954).

122. Schwendler, R.G. and MacNeal, R.H., "Optimum Structural Representation in Aeroelastic Analyses," ASD TR-62-680 (1962).

123. Pearce, B.F., "Topics on Flexible Aircraft Dynamics; Part I: Residual Stiffness Effects in Truncated Model Analysis," ASD TR-63-334 (Pt. 1) (1963).

124. Pass, H.R., Pearce, B.F., and Wolkovitch, J., "Topics on Flexible Aircraft Dynamics; Part III: Coupling of the Rigid and Elastic Degrees of Freedom of an Airframe," ASD Tr-63-334 (Pt. III) (1963).

125. Milne, R.D., "Dynamics of the Deformable Aeroplane," ARC R&M 3345, London (1964).

126. Boulton, I. et al., "Qualitative Structural Design Criteria by Statistical Methods; Vols. I, II and III," AFFDL TR-67-107, Wright-Patterson AFB, Dayton, Ohio (1968).

127. Taylor, A.S., "The Mathematical Foundation for an Integral Approach to the Dynamic Problem of Deformable Aircraft," RAE TR 71131 (1971).

128. Woodcock, D.L., "The Dynamics of Deformable Aircraft, a Simple Approach for Engineers," RAE TR 71227 (1971).

129. Schwanz, R.C., "Formulations of Equations of Motion of an Aeroelastic Aircraft for Stability and Control for Flight Control Applications," AFFDL FGC TM-72-14 (1972).

130. Schmitz, P.D., "Normal Mode Solution to the Equations of Motion of a Flexible Airplane," J. Aircraft, 10 (5), pp 318-320 (1973).

131. Stapleford, R.L. and diMarco, R.J., "A Study of the Effects of Aircraft Dynamic Characteristics on Structural Loads Criteria," STI-TR-1099-1, Systems. Tech. Inc., Hawthorn, CA (1978).

132. Henrick, R.C., "The Sensor Blender Approach to Control Flexible Vehicles," SAE Committee A18 (1964).

133. Smith, R.E., Lum, E.L.S., and Yamamoto, T.G., "Application of Linear Optimal Control Theory to Control the Flexible Aircraft Ride Qualities," AFFDL TR-67-136 (1968).

134. Arnold, J.I., "Automatic Control for Damping Large Aircraft Elastic Vibrations," Proc. NAECON, pp 49-55, Dayton, Ohio (1968).

135. Newberry, C.F., "Consideration of SAS for Large Elastic Aircraft," AGARD CP-46 (1969).

136. Smith, R.E. and Lum, E.L.S., "Linear Optimal Theory Applied to Active Structural Bending Control," AIAA Paper 69-970 (1969).

137. Newberry, C.F., Arnold, J.I., and Kass, G.J., "The Effect of Active Controls on Structural Responses," AGARD Rept. 580 (1971).

138. Sevant, F.D. and Patel, S.M., "Analysis and Testing of Aeroelastic Model SAS - Final Report," NASA CR-132345 (1973).

139. Sellner, J.A., "A Digital Mode Controller for a Large Flexible-Bodied Aircraft," M.S. Thesis, GE/EE/74M-5, USAF Inst. Tech., Wright-Patterson AFB, Dayton, Ohio (1974).

140. Williams, J.G., "Analysis/Theory of Controlled Configured Structures," Rept. 2-53443, LTV Aerospace Corp. (Vought Systems Div.), Dallas, TX (1974).

141. Dressler, W., "Control of an Elastic Aircraft Using Optimal Control Laws," Paper No. 9, AGARD CR-157 (1975).

142. Hoffman, G., "Stabilization, Gust Alleviation and Vibration Damping of an Elastic Aircraft Model Moving in a Wind Tunnel," Ph.D. Thesis, Univ. Brunswick, W. Germany (1976).

143. Konar, A.F. et al., "Active Control Synthesis for Flexible Vehicles; Vol. I: KONPACT Theoretical Description," Rept. 76-SRC-20-Vol. I, Honeywell Inc., Minneapolis (1976).

144. Quade, D.A., "Load and Dynamic Assessment of B-52B-008 Carrier Aircraft for Finned Configuration; Vol. 2: Airplane Flutter and Load Analysis Results," NASA CR-150834 (1978).

145. Matthew, J.R., "Developing, Mechanizing and Testing of a Digital Active Flutter Suppression System for a Modified B-52 Wind-Tunnel Model," NASA CR-159155 (1980).

146. McLean, D. and Prasad, R.A., "A Structural Load Alleviation Control System for a Large Transport Aircraft," TT-8002, Univ. Loughborough, England (1980).

147. Prasad, R.A., "Application of Optimal Control to Structural Load Alleviation Control Systems," Ph.D. Thesis, Univ. Loughborough, England (1980).

148. Balakrishnan, A.V. and Edwards, J.L., "Calculation of the Transient Motion of Elastic Airfoils Forced by Control Surface Motion and Gusts," NASA TM-81351 (1980).

149. Dzygadlo, Z., "Dynamics of Longitudinal Motion of a Variable-Sweepback Aeroplane with a Deformable Control System," J. Tech. Phys., 21 (2), pp 209-224 (1980).

150. Moon, F.C. and Dowell, E.H., "The Control of Flutter Instability in a Continuous Elastic System Using Feedback," AIAA/ASME Proc. 11th Struc. Dynam. Matl. Conf., pp 48-65, Denver, CO (1970).

151. Bartley, J.B. and Turner, M.J., "Advanced Flutter Design Techniques," SAE Paper 730935 (1973).

152. Sisto, F. and Perumal, P.V.K., "Light and Movement Prediction for an Oscillating Airfoil with a Moving Separation Point, J. Engr. Power, Trans. ASME, 96 (4), pp 272-278 (1974).

153. Rajagopal, P., "Simulation au Sol du Flottement pour ses Avions de Grande Allongement," ONERA TN 222, Paris (1974).

154. Rodden, W.P. and Harder, R.L., "Flutter Analysis with Active Controls," NASTRAN Users' Conf., California (1975).

155. Smith, L.S. and Morino, L., "Stability Analysis of Non-Linear Differential Autonomous Systems with Applications to Flutter," AIAA J., 14, pp 333-341 (1976).

156. Sethna, P.R. and Shapiro, S.M., "Non-Linear Behaviour of Flutter Unstable Dynamical Systems with Gyroscopic and Circulating Forces," J. Appl. Mech., Trans. ASME, 44, pp 755-762 (1977).

157. Eastep, F.E. and Olsen, J.L., "Transonic Flutter Analysis of a Rectangular Wing with Conventional Airfoil Section," AIAA J., 18 (10), pp 1159-1164 (1980).

158. Burkhard, A.H., "Simulation of Captive Flight Aircraft Store Vibrations," SAE Paper 730938 (1973).

159. Haidl, G., "Active Flutter Suppression on Wings with External Stores," AGARD 37th Mtg. Struc. Matl. Panel, Paris (1975).

160. Myktow, W.J., "Technical Evaluation Report of AGARD Specialists' Meeting on Wing-with-Stores Flutter," AGARD AG-96, Paris (1976).

161. Whoric, J.M., "Static Stability and Drag Effects of Various External Store Configurations on the F-15 Aircraft at Mach Nos. from 0.6 to 1.3," AEDC-TR-76-63 (1977).

162. Foersching, H., "Einfluss Servomechanischer Steurungs- und Stabilitatsysteme auf das Fluttarverhalten von Flugzeugen," DFVLR-Sonderdruck-272, DFVLR EV Goettingen, W. Germany (1971).

163. Jenney, G.D., "Research and Development of Aircraft Control Actuation Systems. The Development of a Flight Control System Simulator, Research on a Control Surface Flutter Suppression Technique," Rept. Dynam. Control Inc., Dayton, Ohio (1975).

164. Destuynder, R., "Test and Analysis of an Active Flutter Suppression on a FFDL Model of YF-17," AGARD R-698, Paris (1980).

165. Daschund, D.E., "The Development of a Theoretical and Experimental Model for the Study of Active Suppression of Wing Flutter," Ph.D. Thesis, Princeton (1981).

166. Rustenburg, J.W., "Ride Quality Design Criteria for Aircraft with Active Mode Control Systems," ASD TR-72-64 (1972).

167. Broderson, A.B., Von Giercke, H.E., and Guignard, J.C., "Ride Evaluation in Aerospace and Surface Vehicles," NASA TM-X-2620 (1972).

168. Stephens, D.G., "Development and Application of Ride Quality Criteria," SAE Paper 740813 (1974).

169. Swaim, R.L. et al., "An Analytical Method for Ride Flexible Airplanes," AIAA J., 15 (1), pp 4-7 (1977).

170. Swaim, R.L., "Handling Qualities of Large Flexible Control Configured Aircraft," NASA CR-163206 (1980).

171. Chu, Min-Kwang, "The Shaking in Flight," FTD-ID(RS)T-2079-78, F.T.D., Wright-Patterson AFB, Dayton, Ohio (1978).

172. Stirling, R., "The Application of Pilot Models and Automatic Ride Control to Flight in Turbulence and Their Effects on Structural Loads," Ph.D. Thesis, Univ. Bristol, England (1976).

173. Pollard, J.J., "All Digital Simulation for Manned Flight in Turbulence," AFFDL-TR-75-82 (1975).

174. Frost, W. and Crosby, B., "Investigations of Simulated Flight through Thunderstorms Outflows," NASA CR-3052 (1978).

# WIND EXCITED BEHAVIOUR OF STRUCTURES III

**D.J. Johns***

***Abstract.*** ***This article reviews recent literature on wind-excited behavior of structures. Among the phenomena considered are those due to vortex shedding, galloping, flutter, divergence, and turbulence. Theoretical and experimental (model and full scale) studies are included as are techniques to alleviate wind excited behavior.***

Earlier review articles [1, 2] discussed the technical literature related to the dynamic response and aeroelastic behavior of typical structural forms through 1978. The present paper reviews the literature from 1979 through 1981. Most references are listed in tables 1 and 2. They are intended to help the specialist find the literature on a specific structural form or flow-excited phenomenon.

## THE NATURE OF WIND

Several publications present useful information on the current state of knowledge on the nature of wind (see Table 2). High winds, tornadoes, and hurricanes have been described [36] as has a laboratory simulation of steady tornadic winds and some results on tests on model structures [90]. Useful introductions to the nature of wind are available [72, 75]. Other timely reviews have appeared [14, 176]. Simulations of the mean and turbulent properties of an urban boundary layer wind have been presented [28, 81]. An improved model of natural wind has been reported [83]; the commonality of seismic and wind analysis has been considered [103]. Other useful references are available [39, 172, 175-178].

## MECHANISMS

Wind-excited responses considered below include those due to vortex shedding and the subsequent in-line and cross-flow bending oscillations; ovalling oscillations; torsional oscillations; galloping oscillations; flutter, divergence (buckling); and turbulence effects. These phenomena have been described [1, 2].

Special mechanisms for wind-excited response that have been considered include simulation of tornadic winds [90]; localized pressure fluctuations due to cavities typical of irregularities in external shapes of buildings [120]; and aerodynamics of two parallel circular cylinders [152] and of roofing elements [154].

A rational consistent nonlinear oscillator model has been suggested [163] that takes into account the known theoretical and experimental behavior of the fluid. Results for such a model have been compared with those obtained from the Skop-Griffin model. The results are broadly similar, but the published method for determining the coefficients from the Skop-Griffin model is physically inconsistent. Means for determining the coefficients from particular experiments have been suggested and comparisons with existing data have shown encouraging agreement. Useful critiques of such models have appeared [174].

## VORTEX SHEDDING

Basic data on vortex shedding have been given [1, 2]. Several excellent reviews were published during the period from 1979 through 1981. Much of the available information in the form of data sheets in a readily and easily usable form has been summarized [41]. Other reviews consider synchronization, cross flow, and in-line responses [55], cross-flow responses [98], and in-line responses [126].

Information on the flow around, and the fluctuating loads on, fixed circular cylinders in uniform streams,

*Professor of Aeronautics, Head of Department of Transport Technology, The University of Technology, Loughborough, Leicestershire, LE11 3TU, England

including the effects of free stream turbulence and surface roughness, has been presented [128]. Drag, lift, and pressure coefficient data are also presented.

Surveys of experimental data applicable to circular and non-circular cylinders as well as the governing analysis are available [137, 138]. The significant effect of cylinder vibration -- i.e., its modification of both periodic and steady forces due to vortex shedding is shown.

***In-line and cross-flow bending oscillations.*** References for in-line and cross-flow responses are listed in Table 2. Fluid damping in the drag (and lift) directions have been presented as a function of reduced-flow velocity together with detailed response characteristics [8]. Natural frequencies of circular cylindrical shells relevant to in-line and cross-flow bending -- and ovalling oscillations -- have been given [45]. Additional in-line data are available [55, 84].

A theoretical attempt has been made to obtain a method for predicting response amplitudes. A stability criterion that has been derived indicates that instability is to be expected only over a range of Reynolds number close to a critical value at which the drag coefficient drops suddenly and the Strouhal number increases suddenly. Comparisons with experiments are also reported for in-line data [126].

Data have been presented for elliptic cylinders [3] and square and H sections [6, 22, 125] in cross flow. Bridge sections have been studied [21, 109], but the majority of papers relate to circular sections typical of chimneys. An excellent summary of available data has been presented in a convenient form [41].

A mathematical model has been proposed [42] in connection with measurements made of the structural damping and cross-wind response amplitudes for several configurations of bluff cylinders. Some tests in flowing water were also used.

Wake oscillator models applicable to cross-flow response and mechanisms for in-line oscillations have been reviewed [55]. A mathematical model has been developed for the prediction of vortex-excited resonant responses of two cylinders in the line of wind direction [61].

Circular and square tower models have been tested, analyzed, and reported [125]. The tests were conducted in a boundary layer wind tunnel representing a typical suburban-type wind model. A prediction procedure consisting of a random excitation and a sinusoidal lock-in excitation model was derived and gave good agreement with measured data.

A semi-empirical modeling approach based on a fluid momentum theorem and on assumptions regarding the nature of the coupling between the fluid and the structure has been presented [132]. This model is also applicable to high mode number resonances in cables.

A thorough survey of the entire topic of wind effects on structures and of literature published before 1978 is available [175]. Sections on vortex shedding – particularly in-line and cross-flow responses – are especially useful. Non-circular sections are thoroughly covered as are the effects of free-stream turbulence and proximity of other structures.

Table 1 lists relevant references dealing with problems of arrays of cylinders. Although some are directly concerned with water or other flowing fluids and with problems of nuclear reactors, they are quoted for their probable relevance to wind-excited structures.

***Ovalling oscillations.*** Only one significant publication since 1977 deals with the mechanism of ovalling [51]. It contains results of a thorough experimental investigation, a critical analysis of the data, and a comparison with work of earlier researchers. Much of the data support the earlier findings; the noteworthy exception is that ovalling is probably not caused by vortex shedding. This conclusion is based on the observation that ovalling occurred on identical shells and at similar flow velocities whether or not a longitudinal splitter plate was in position to prevent asymmetric vortex shedding. Comments on these results have appeared [162].

Charts and other data have been published that allow natural frequencies to be calculated for a wide range of shell configurations in ovalling and other cross-sectional deformation modes [45].

***Torsional oscillations.*** Torsional oscillations can be a consequence of vortex shedding, galloping, single-degree-of-freedom flutter, or classical flutter. This section is mainly concerned with vortex shedding.

Cross-flow bending and/or torsional oscillations can occur when channel and I- or H-section members are subjected to winds normal to a flange [175]. Other studies have been published [21, 40, 74, 80, 119, 121, 129, 140, 160].

Two-dimensional rectangular cylinders have been studied in a uniform, two-dimensional flow [119]. Both the free oscillation method and the forced oscillation method were used. Data showed the effect of thickness to chord, or width to length, ratio.

Expressions have been derived in which the torsional forcing function is based on numerical integration of the spatio-temporal characteristics of measured pressure calculations [121]. One method [129] is based on random vibration concepts and aerodynamic admittance functions. They were used to estimate the spectral density function of the random torque and the cross-spectral density function of the force and torque acting on the structure. The force and torque were used to calculate the dynamic torsional response. Similar data have been published [160].

## GALLOPING OSCILLATIONS

The basic mechanisms underlying galloping are well understood [1, 2, 175]. An experimental and analytical study [111] describes galloping of a two-dimensional section model of a two-conductor bundle in which ice-accreted conductors were replaced by two identical square prisms. Vertical and torsional movements only were allowed. It was shown that, in addition to galloping, torsional and classical type flutter can occur for bundled conductors. The influence of nonlinear terms in the equations of motion on the first normal modes of an elastic flexible cable under the action of gravity have been studied relative to galloping of transmission lines [112].

It has been concluded [142] that a square section prism will gallop and the amplitude will increase linearly with velocity as predicted by quasi-steady theory at flow velocities greater than two or three times resonance. The same linear trend has been observed for lower velocities around resonance; quasi-steady theory is therefore useful in predicting galloping under all conditions. Other relevant publications have appeared [147, 161].

## FLUTTER

Classical flutter can occur when two or more distinct elastic modes couple even if all individual aerodynamic dampings are positive. Various non-aeronautical structural forms -- typically slender bridge sections -- have exhibited this phenomenon. It has been shown [2] that such sections can also show single-degree-of-freedom flutter under certain conditions. A good exposition of basic theory and a simple physical explanation of classical flutter have been given [175].

Excellent review papers are available [10, 172, 174, 176]. Specific studies are listed in Table 2. Useful information relevant to bridges has appeared [58, 109]. The importance of drag terms in classical flutter analysis has been shown [93].

The results of a theoretical and experimental study of two particular configurations of non-circular sections of a transporter bridge have been presented [167]. Structural modeling of the sandwich-type construction used in the full-scale structure was not complete; mass scaling only was achieved in the model. The model was made flexible with a base support flexure. Cross-wind vibrations were in general consistently greater than in-line vibrations for both configurations. When the torsional frequency was much higher than the bending frequencies, classical flutter was considered less likely than galloping oscillations. Vortex-excited oscillations were also found.

Wake flutter of cylinders close to each other has also been reported. A summary of available information is available [84], as are additional data [170]. Coupled cylindrical conductors have been dealt with [105]. When the windward conductor is fixed and the leeward conductor is elastic, flutter occurs. In a more general study the windward conductor was also free to move [176].

## DIVERGENCE (BUCKLING)

Relatively little information has recently been published on divergence or buckling. The structural mechanics of a nonlinear shell theory applicable to cooling tower shells have been considered [19] and would be applicable to static failure analysis. Structural problems caused by wind pressure have been considered [27].

A stability analysis for wind loaded cooling tower shells has been reported [50]. Alternative approaches show good agreement. Failure modes of several common building types have been discussed [70]. Experimental data for buckling due to wind of circular cylindrical shells supported at various lengthwise support positions typical of wind shields for tall antenna mats have been presented [169]. An optimum support position was found with the supports at 0.22 x length from each free end.

## TURBULENCE EFFECTS

Numerous publications on turbulence have appeared [Table 2]. Turbulence in the incident flow can have a significant effect on such flow excitation phenomena as vortex shedding [2, 6, 9, 101, 110, 128, 175].

The major consideration for turbulence is the broadband excitation of structures due to free stream turbulence; the problem is usually treated as a stationary random process on a probabilistic basis. Basic treatments of this problem have appeared [174-176], as has a comprehensive exposition of current thinking [177].

Such parameters as site roughness, structural size, and simple dynamic properties can be used to classify structures [178].

Class A: Structures and/or elements sufficiently stiff so that wind effects can be determined by statics and small enough so that relevant wind information can be specified as a wind speed at a single point.

Class B: Structures stiff enough so that wind effects can be determined by statics but large enough to require wind information to be specified as multi-point data.

Class C: As for B, but with the additional complication that the shapes of individual structural load influence lines must be considered in conjunction with multi-point data.

Class D: Structures that are not stiff enough to be treated by static methods but require a full dynamic treatment.

Class E: Structures, generally called aeroelastic, for which wind, aerodynamic, and structural motion are inseparably combined to produce overall wind effects.

Different approaches for analysis or testing are required for these various classes of structure. There is need for unification of codes of practice currently in use. Many national codes contain provisions for dynamic response of structures, but the approaches, quality of information, and results differ substantially [177].

Information on bridges has appeared [11, 12, 21, 34, 35, 62, 66, 69, 72, 76, 91, 92, 107, 117], as has information on towers and masts [18, 47, 52, 53, 64, 144, 146]. A significant body of literature is available on cooling tower structures (20, 46, 67, 85-88, 95, 166].

For design purposes, particularly for codes of practice, there is a need for simple means to relate the dynamic situation of turbulent wind and elastic structures. Several approaches have been discussed in the literature [141, 155, 177].

## FULL-SCALE DATA

References on full-scale data can be divided by structural configuration into chimneys [30, 114], buildings [63, 70, 77, 150], bridges [106, 109], towers and masts [29, 122, 130, 136, 146], cooling towers [85, 86, 95], and transmission lines/cables [104].

The main concern for chimneys and buildings has been to determine natural frequency and damping parameters [30, 63, 77, 114] or to relate observed failure modes due to wind damage with building type [70].

Four system identification methods have been used [77] to analyze ambient data; they are filtered correlation, spectral moments, spectral density, and two-stage least squares. Long-term measurements have been used to determine the effect on fatigue life of the Wye Bridge [106]. Full-scale vibration measurement has been related to corresponding wind tunnel tests [109].

Studies reported on towers and masts [29] are a prelude to investigating suitable remedial measure

to reduce wind-excited oscillations. Static and dynamic responses, local surface pressures, and wind characteristics have been reported [122, 130, 136].

Wind pressure measurements have been made for cooling towers [85, 86]. Strain gages have been used to measure shell response [95]. Results suggest that considerable bending occurs in the circumferential stresses.

## TECHNIQUES TO MINIMIZE WIND-EXCITED DYNAMIC RESPONSE

The dynamic equations of motion for a structure involve inertia, damping, stiffness, and aerodynamic input. Techniques to alleviate dynamic response are developed by modifying one or more of these parameters in a given problem.

Several methods have been used to modify aerodynamic input. One method for preventing vortex-excited oscillations is to perforate the structure to allow venting of the oncoming stream into the wake. Other methods include using a separate concentric perforated shroud; a helical strake system; or an externally mounted vertical slat system [2, 151, 175]. A comprehensive review of various aerodynamic methods for suppressing vortex shedding is available [159].

Modifications of the mass of a system can change natural frequencies and/or mode shape. Stiffness modifications are possible but can be accompanied by corresponding changes in mass with little or no consequent frequency change. The addition of guys to a free-standing structure can improve frequencies with minimal weight increase,but this technique is not always feasible.

Changes in effective damping can be made [2]. Such techniques are usually passive, but interest in active control techniques is increasing. The concept of modal control has been offered as a possible design technique for active structural control systems [5]. Direct changes can be produced in specific dynamic modes and in the stiffness of the system only when a limited number of separable modes is involved. Structural safety, desired human comfort, and control feasibility have been studied [73]. An optional control problem has been formulated; it was shown that a closed-loop control can be obtained in the presence of certain inequality constraints.

Active control of a suspension bridge subjected to buffeting and self-excited loads has been studied [12]. Existing suspension cables were used as active tendons by which control forces could be applied to the bridge deck at anchorage points. The control force was regulated by the sensed motion of the bridge deck at the cable anchorage. Stability, steady-state responses, and power requirements have been considered.

Applications to actual and hypothetical bridge structures have been made [62]. Design guides with design charts that provide mathematical theories and illustrative examples for mitigating damage due to fatigue under vortex-excited conditions have been recommended [21]. The members considered can have different levels of axial tension, various degrees of end fixity, and be subject to both flexural and torsional vibrations.

A closed-loop control system has been designed for a simplified structural model [89]. Its efficiency can be checked in relation to those factors that were neglected in order to make the model simple.

Transmission line problems have been considered. Various forms and positions of dampers have been considered to determine the effects on maximum strains produced for assumed wind power input [7]. A brief review article is also available [13]. Theoretical results have been combined with experimental data to assess the efficiency of design mechanisms for reducing vibration [116]. Optimum designs for reducing galloping have been studied [164].

Three methods have been described for avoiding vortex-excited oscillations in chimneys [30]. Comparisons were made between aerodynamic and damping devices. Special damping pads in chimney foundations have been analyzed [114]. Allowance for soil-structure interaction was made; a significant increase in effective damping was reported. The benefits of reducing vortex excitation were shown, but caution is necessary with regard to static deformation criteria.

Table 1. References Dealing with Structural Configuration

| STRUCTURE | REFERENCES |
|---|---|
| ISOLATED CIRCULAR CHIMNEYS/ CYLINDERS | 8, 24, 30, 41, 42, 45, 51, 55, 56, 61, 90, 98, 99, 110, 114, 124, 126, 128, 132, 137, 138, 143, 157, 162, 168 |
| ARRAYS OF CYLINDERS | 9, 61, 79, 84, 99, 105, 151, 158, 170 |
| NON-CIRCULAR CYLINDERS | 3, 22, 33, 37, 90, 119, 124, 133, 156 |
| BUILDINGS | 5, 6, 15, 16, 17, 23, 26, 27, 28, 31, 34, 35, 36, 38, 39, 52, 53, 57, 59, 63, 70, 73, 74, 77, 78, 80, 83, 91, 92, 97, 115, 118, 121, 124, 129, 131, 135, 150, 153, 160 |
| BRIDGES | 10, 11, 12, 15, 21, 22, 25, 32, 34, 35, 40, 58, 62, 66, 69, 72, 76, 80, 82, 89, 91, 92, 93, 100, 106, 107, 109, 117, 140, 167 |
| TOWERS AND MASTS | 18, 29, 47, 52, 53, 64, 65, 113, 122, 130, 136, 142, 143, 144, 146, 169 |
| COOLING TOWERS | 19, 20, 46, 50, 67, 75, 85, 86, 87, 88, 95, 166 |
| TRANSMISSION LINES AND CABLES | 7, 13, 47, 54, 65, 101, 104, 111, 112, 116, 123, 132, 147, 161, 164 |
| ROOFS AND CLADDING | 24, 43, 71, 134, 145, 154 |
| FLOATING STRUCTURES | 60, 94, 127 |

Table 2. References Dealing with Phenomena

| PHENOMENON | REFERENCES |
|---|---|
| NATURE OF WIND | 15, 16, 18, 28, 36, 81, 83, 87, 90, 139, 141, 149, 155 |
| SPECIAL FLUID MECHANISMS | 90, 120, 152, 154, 163 |
| VORTEX SHEDDING: | |
| IN LINE | 8, 45, 55, 84, 104, 126 |
| CROSS FLOW | 3, 8, 9, 21, 22, 24, 30, 33, 41, 42, 44, 45, 55, 61, 68, 79, 82, 84, 98, 99, 104, 109, 110, 114, 125, 128, 132, 133, 137, 138, 143, 156, 157, 158, 165, 168, 169, 170 |
| OVALLING VIBRATIONS | 45, 51, 162 |
| TORSIONAL VIBRATIONS | 21, 40, 74, 80, 119, 121, 129, 140, 160 |
| GALLOPING VIBRATIONS | 33, 42, 111, 112, 142, 147, 161 |

(continued)

Table 2 (continued)

| PHENOMENON | REFERENCES |
|---|---|
| FLUTTER | 10, 12, 25, 31, 32, 58, 84, 93, 105, 109, 167, 170 |
| DIVERGENCE & BUCKLING/ STATIC STRESS | 19, 27, 28, 50, 70 |
| TURBULENCE/FATIGUE | 6, 9, 11, 12, 18, 20, 23, 26, 28, 34, 35, 38, 43, 46, 47, 48, 49, 52, 53, 56, 57, 59, 60, 61, 62, 64, 66, 67, 69, 71, 72, 74, 76, 81, 83, 87, 88, 91, 92, 94, 95, 97, 101, 102, 103, 107, 108, 110, 113, 115, 117, 121, 123, 124, 128, 129, 131, 134, 144, 145, 148, 153 |
| FULL SCALE TESTING | 29, 30, 63, 70, 77, 85, 86, 95, 104, 106, 109, 122, 130, 136, 146, 150 |
| ALLEVIATION TECHNIQUES | 5, 7, 12, 13, 21, 27, 29, 30, 33, 62, 73, 89, 114, 116, 151, 159, 164 |

## DISCUSSION AND CONCLUSIONS

The literature since 1979 has been cited and reviewed. Significant advances have been made in analysis, collecting full-scale data, and design procedures for passive and active control systems. It is to be hoped that before long international design codes for the various classes of structures will be available.

## REFERENCES


1. Johns, D.J., "Wind Excited Behavior of Structures," Shock Vib. Dig., 8 (4), pp 67-75 (Apr 1976).

2. Johns, D.J., "Wind Excited Behavior of Structures II," Shock Vib. Dig., 11 (4), pp 17-29 (Apr 1979).

3. Modi, V.J. and Leong, L., "On Some Aspects of Unsteady Aerodynamics and Vortex Induced Oscillations of Elliptic Cylinders at Subcritical Reynolds Number," J. Mech. Des., Trans. ASME, 100 (2), pp 354-362 (Apr 1978).

4. Abdelrahman, A.M.S.A., "Dynamic Response of Structures in Frequency Domain," Ph.D. Thesis, Polytechnic Inst. of New York (1978).

5. Martin, C.R., "A Modal Control Approach for Active Control of Multi-Story Structures," Ph.D. Thesis, State Univ. of New York at Buffalo (1978).

6. Robeson, J.A. and Crowe, C.T., "Effect of Turbulence on the Pressure Distribution and Vibration of Angular Bodies; Part 1: Pressure Distribution on Model Buildings at Small Angles of Attack in Turbulent Flow; Part II: The Aeroelastic Vibration of the Square and H-Shaped Sections in Turbulent Cross Flows," Washington State Univ., Pullman, WA, Rept. No. TR/HY-1/78 (Mar 1978).

7. Dhotarad, M.S., Ganesan, N., and Rao, B.V.A., "Transmission Line Vibrations," J. Sound Vib., 60 (2), pp 217-237 (Sept 1978).

8. Chen, S.S. and Jendrzejczyk, J.A., "Dynamic Response of a Circular Cylinder Subjected to Liquid Cross Flow," ASME Paper No. 78-PVP-15.

9. Weaver, D.S. and Grover, L.K., "Cross Flow Induced Vibrations in a Tube Bank," ASME Paper No. 78-PVP-25.

10. Scanlan, R.H., "The Action of Flexible Bridges Under Wind; I: Flutter Theory," J. Sound Vib., 60 (2), pp 187-199 (Sept 1978).

11. Scanlan, R.H., "The Action of Flexible Bridges Under Wind; II: Buffeting Theory," J. Sound Vib., 60 (2), pp 201-211 (Sept 1978).

12. Giannopoulos, F., "Dynamic Analysis and Active Control of Two Cable-Stayed Bridge," Ph.D. Thesis, Virginia Inst. and State Univ. (1978).

13. Ramamurti, V., Sathikh, S., and Chari, R.T., "Transmission Line Vibrations," Shock Vib. Dig., 10 (11), pp 27-31 (Nov 1978).

14. Natke, H.G. (Ed.), "Aeroelastic Problems Outside Aeronautics and Astronautics," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78 (Mar 1978).

15. Hirtz, H., "Design Standardization for Wind Loads," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 450-458 (Mar 1978) (in German).

16. Gerasch, W.J., "Critical Evaluation of the German Standard DIN 4133 by Considering Measurement Results Taken at Natural Wind Conditions," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 581-606 (Mar 1978) (in German).

17. Jeary, A.P., "The Estimation of Reliable Spectral Information When Recording Low Intensity Data," J. Sound Vib., 60 (3), pp 401-409 (Oct 1978).

18. Lawsen, H.I. and Kempner, L., "Response of a Latticed Transmission Tower to Wind," Dept. Civil Engrg., Oregon State Univ., Rept. No. HIL/OSU/BPA-1 (Sept 1977).

19. Kratzig, W.B., "Shell-Type Response of Cooling Towers - State of the Art and Open Questions," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 72-83 (Mar 1978) (in German).

20. Niemann, H.J., "Turbulence Induced Shell Vibrations of Reinforced Concrete Cooling Towers," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 538-560 (Mar 1978) (in German).

21. Chi, M., "Response of Bridge Structural Members Under Wind-Induced Vibrations," Chi Assoc. Inc., Arlington, VA, Rept. No. FHWA/RD-78/25 (June 1976).

22. Chi, M., Neal, E., and Dennis, B.G., "Determination of Strouhal Characteristics and Power Spectrum for Elastically Restrained H-Shape Sections," Chi Assoc. Inc., Arlington, VA, Rept. No. FHWA/RD-78/26 (Aug 1977).

23. Konig, G., "Design of Reinforced Wind-Resistant Structural Components for Tall Buildings," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 459-482 (Mar 1978) (in German).

24. Quadflieg, H. and Mankau, H., "Variable Vibration Damping of Flat and Prismatic Bodies in Stationary and Moving Air," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 164-186 (Mar 1978) (in German).

25. Thiele, F., "The Analysis of Aerodynamic Stability of Bridges, For Example, The Bridge on River Rhine between Dusseldorf and Flehe," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 561-580 (Mar 1978) (in German).

26. Zilch, K., "Design of Tall Wind-Resistant Buildings, Especially Regarding Their Serviceability," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 483-503 (Mar 1978) (in German).

27. Petersen, C., "Problems, Solutions and Failures in Construction and Aeroelasticity," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 424-449 (Mar 1978) (in German).

28. Reinhold, T.A., Sparks, P.R., Tieleman, H.W., and Maher, F.J., "The Effect of Wind Direction on the Static and Dynamic Wind Loads on a Square Section Tall Building," Proc. 3rd Colloq. Indus. Aerodynam., Aachen, Germany (June 1978).

29. Hertzog, H., "Guyed Masts," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 504-518 (Mar 1978) (in German).

30. Ruscheweyh, H., "Measures for the Prevention of Dangerous Chimney Vibrations," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 519-537 (Mar 1978) (in German).

31. Hennlich, H.H. and Rosemeier, G., "Numerical Investigation of Flutter of Linear Frameworks in the Building Industry," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 352-371 (Mar 1978) (in German).

32. Mahrenholtz, O., "The Mechanisms of Aeroelasticity," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 5-16 (Mar 1978) (in German).

33. Bardowicks, H. and Mahrenholtz, O., "Aeroelastic V brations of Sharp-Edged Prismatic Bodies," Proc. Mtg. at Tech. Univ. Hanover, Fed. Rep. Germany, Rept. No. CRI-K1/78, pp 281-299 (Mar 1978) (in German).

34. Habercom, G.E., Jr., "Wind Effects; Part 1: Buildings and Bridges," NTIS/PS-78/1209/2GA (Nov 1978).

35. Habercom, G.E., Jr., "Wind Effects; Part 1: Buildings and Bridges," NTIS/PS-78/1207/6GA (Nov 1978).

36. NSF-DCPA-ASEE Summer Inst. on Multiprotection Design (1977), Amer. Soc. Engrg. Educ., Washington, DC, Rept. No. NSF/RA-770633 (Aug 1977).

37. Greenway, M.E. and Wood, C.J., "Energy Constraints in Vortex-Excited Vibrations," J. Sound Vib., 61 (2), pp 179-204 (Nov 1978).

38. McDonald, J.R. and Lea, P.A., "A Study of Building Damage Caused by Wind Forces," Inst. Disaster Res., Texas Tech. Univ., Lubbock (Jan 1978).

39. Lew, H.S., "Wind and Seismic Effects," Proc. 9th Joint Panel Conf. U.S. - Japan Coop. Program Natural Res., Tokyo, May, 1977, Natl. Bureau Stds. Rept. NBS-SP-523 (Sept 1978).

40. Sofronie, R., "Dynamic Distribution of Lift on Suspension Bridges,"Mecanique Appliquee, 23 (6), pp 925-938 (Nov/Dec 1978).

41. "Across-flow Response Due to Vortex Shedding: Isolated Circular Cylindrical Structures in Wind or Gas Flows," Engrg. Sci. Data Unit, Ltd., London, UK, Rept. ESDU-78006 (Oct 1978).

42. Griffin, O.M., "Vortex-Excited Unsteady Forces on Resonantly Vibrating, Bluff Structures," Naval Res. Lab., Washington, DC, Rept. No. NRL-MR-3820, AD-E000 231 (Aug 1978).

43. Yun, C.B., Abdelrahman, A.M., and Wang, P.C., "Along-Wind Gust Effect on Elevated Structures," Engrg. Struc., 1 (3), pp 121-124 (Apr 1979).

44. Howell, J.F., "Soil-Structure Interaction Under Wind Loading," Ph.D. Thesis, Univ. Western Ontario (1978).

45. "Natural Frequencies of Thin-walled Isotropic, Circular-Cylindrical Shells," Engrg. Sci. Data Unit, Ltd., London, UK, Rept. ESDU-78004 (1978).

46. Verma, U.S.P., Akolkar, P.M., and Warudkar, A.S., "Comparative Evaluation of Wind and Seismic Loads for N.D. Cooling Tower," Symp. Earthquake Engrg., Univ. of Roorkee, India, pp 485-488 (Oct 1978).

47. Rangaswami, R., Jayaraman, G., Senthakumar, A.R., and Jayesekaran, T., "Dynamic Loads on Transmission Line Towers," Symp. Earthquake Engrg., Univ. of Roorkee, India, pp 458-460 (Oct 1978).

48. "DAFT: A Dynamic Analysis Computer Program," Arup (Ove) and Partners, London, UK (1978).

49. Williamson, G., "Gust Load Estimation Using a Simplified Power Spectral Technique," Final Rept., Apr 1977 - Apr 1978, Aeronaut. Res. Assoc. Princeton, NJ, Rept. No. ARAP-362; FAA-RD-78-118 (Oct 1978).

50. Mang, H., Gallagher, R.H., Cedolin, L., and Torzicky, P., "Deformation and Stability of Wind-Loaded Cooling Tower Shells," Ing. ARch., 47 (6), pp 391-410 (1978) (in German).

51. Paidoussis, M.P. and Helleur, C., "On Ovalling Oscillations of Cylindrical Shells in Cross-Flow," J. Sound Vib., 63 (4), pp 527-542 (Apr 1979).

52. Joseph, M.G. and Radhakrishnan, R., "A Response Spectrum for Dynamic Effects of Wind on Tall Structures," Symp. Earthquake Engrg., Univ. of Roorkee, India, pp 495-498 (Oct 1978).

53. Joseph, M.G. and Radhakrishnan, R., "A Rigorous Elastic Response Analysis of Tall Structures Subjected to Dynamic Wind Loads," Symp. Earthquake Engrg., Univ. of Roorkee, India, pp 517-522 (Oct 1978).

54. Migliore, H.J. and Webster, R.L., "Current Methods for Analyzing Dynamic Cable Response," Shock Vib. Dig., 11 (6), pp 3-16 (June 1979).

55. Sarpkaya, T., "Vortex-Induced Oscillations. A Selective Review," J. Appl. Mech., Trans. ASME, 46 (2), pp 241-258 (June 1979).

56. Yang, T.Y., Shiau, L.C., Lo, H., and Bogdanoff, J.L., "Theoretical Study of the Dynamic Response of a Chimney to Earthquake and Wind," School Aeronaut. Astronaut., Purdue Univ., Lafayette, IN, Rept. No. NSF/RA-780527 (Apr 1978).

57. Kareem, A., "Wind Excited Motion of Buildings," Ph.D. Thesis, Colorado State Univ. (1978).

58. Simiu, E. and Scanlan, R.H., "Flutter of a Plate-Like Member in Horizontal Fluctuating Flow," Engrg. Struc., 1 (4), pp 207-210 (July 1979).

59. Simiu, E. and Lozier, D.W., "The Buffeting of Tall Structures by Strong Winds, Windload Program," Natl. Engrg. Lab. (NBS), Washington, DC, Rept. No. NBS/DF-79/001 (1979).

60. Fang, S.S., "Response Analysis of a Moored Open-Bottom Floating Platform to Random Loadings," Ph.D. Thesis, Columbia Univ. (1979).

61. Shiau, L., "Theoretical Study of the Dynamic Response of a Chimney to Earthquake and Wind," Ph.D. Thesis, Purdue Univ. (1978).

62. Yang, J.N. and Giannopoolous, F., "Active Control and Stability of Cable-Stayed Bridge," ASCE J. Engrg. Mech. Div., 105 (EM4), pp 677-694 (Aug 1979).

63. Gersch, W. and Martinelli, F., "Estimation of Structural System Parameters from Stationary and Non-Stationary Ambient Vibration. An Exploratory-Confirmatory Analysis," J. Sound Vib., 65 (3), pp 303-318 (Aug 1979).

64. Chakrabarti, S.K. and Cotter, D.C., "Motion Analysis of Articulated Tower," ASCE J. Waterway Port Coastal and Ocean Div., 105 (WW3), pp 281-292 (Aug 1979).

65. Peyrot, A.H. and Goulois, A.M., "Analysis of Cable Structures," Computers Struc., 10 (5), pp 805-813 (Oct 1979).

66. Lu, Z., "Dynamic Analysis of Cable Hung Ruck-A-Chucky Bridge," ASCE J. Struc. Div., 105 (ST10), pp 2009-2018 (Oct 1979).

67. Gould, P.L., "Environmental Loadings on Concrete Cooling Towers - Types, Likelihoods, Effects and Consequences," Engrg. Struc., 1 (5), pp 258-263 (Oct 1979).

68. Holmes, P.J., "Domains of Stability in a Wind-Induced Oscillation Problem," J. Appl. Mech., Trans. ASME, 46 (3), pp 672-676 (Sept 1979).

69. Yang, J.N. and Giannopolous, F., "Active Control of Two-Cable Stayed Bridge," ASCE J. Engrg. Mech. Div., 105 (EM5), pp 795-810 (Oct 1979).

70. Minor, J.E. and Mehta, K.C., "Wind Damage Observations and Implications," ASCE J. Struc. Div., 105 (ST11), pp 2279-2291 (Nov 1979).

71. Beck, V.R. and Stevens, L.K., "Wind Loading Failures of Corrugated Roof Cladding," Instn. Engr. Austral. C.E. Trans., CE21 (1), pp 45-56 (1979).

72. Lin, Y.K., "Motion of Suspension Bridges in Turbulent Winds," ASCE J. Engrg. Mech. Div., 105 (EM6), pp 921-932 (Dec 1979).

73. Abdel-Rohman, M. and Leipholz, H.H.E., "General Approach to Active Structural Control," ASCE J. Engrg. Mech. Div., 105 (EM6), pp 1007-1023 (Dec 1979).

74. Patrickson, C.P. and Friedmann, P.P., "Deterministic Torsional Building Response to Winds," ASCE J. Struc. Div., 105 (ST12), pp 2621-2637 (Dec 1979).

75. Pister, K.S. (Ed.), Structural Engineering and Structural Mechanics, Prentice-Hall (1980).

76. Fleming, J.F. and Egeseli, E.A., "Dynamic Behavior of a Cable-Stayed Bridge," Intl. J. Earthquake Engrg. Struc. Dynam., 8 (1), pp 1-16 (Jan/Feb 1980).

77. Tuoka, G.T., "System Identification of Tall Vibrating Structures," Dept. Civil Engrg., Hawaii Univ., Honolulu, Rept. No. NSF/RA-790173 (July 1979).

78. "Recommendations for a U.S. - Japan Cooperative Research Program Utilizing Large Scale Testing Facilities," Earthquake Engrg. Res. Ctr., California Univ., Richmond, Rept. No. UCB/EERC-79/26 NSF/RA-790241 (Sept 1979).

79. Jendrzejczyk, J.A., Chen, S.S., and Wambsganss, M.W., "Dynamic Responses of a Pair of Circular Tubes Subjected to Liquid Cross Flow," J. Sound Vib., 67 (2), pp 263-273 (Nov 1979).

80. Nakamura, Y., "On the Aerodynamic Mechanism of Torsional Flutter of Bluff Structures," J. Sound Vib., 67 (2), pp 160-177 (Nov 1979).

81. Kareem, A. and Cermak, J.E., "Wind Tunnel Simulation of Wind-Structure Interactions," ISA Trans., 18 (4), pp 23-41 (1979).

82. Maher, F.J. and Wittig, L.E., "Aerodynamic Response of Long H-Sections," ASCE J. Struc. Div., 106 (ST1), pp 183-197 (Jan 1980).

83. Simiu, E., "Revised Procedure for Estimating Along-Wind Response," ASCE J. Struc. Div., 106 (ST1), pp 1-10 (Jan 1980).

84. "Fluctuating Response of Circular Cylinders in Small Groups in Fluid Flow - Discussion and Guide to Data Available," Engrg. Sci. Data Unit, Ltd., London, UK, Rept. ESDU-79025 (1979).

85. Basu, P.K. and Gould, P.L., "Cooling Towers Using Measured Wind Data," ASCE J. Struc. Div., 106 (ST3), pp 579-600 (Mar 1980).

86. Sollenberger, N.J., Scanlan, R.H., and Billington, D.P., "Wind Loading and Response of Cooling Towers," ASCE J. Struc. Div., 106 (ST3), pp 601-621 (Mar 1980).

87. Armitt, J., "Wind Loading on Cooling Towers," ASCE J. Struc. Div., 106 (ST3), pp 623-641 (Mar 1980).

88. Niemann, H., "Wind Effects on Cooling Tower Shells," ASCE J. Struc. Div., 106 (ST3), pp 643-661 (Mar 1980).

89. Abdel-Rohman, M. and Leipholz, H.H., "Automatic Active Control of Structures," ASCE J. Struc. Div., 106 (ST3), pp 663-677 (Mar 1980).

90. Jischke, M.C. and Light, B.D., "Laboratory Simulation of Steady Tornadic Wind Loads on Structures," School Aerospace, Mech. and Nucl. Engrg., Oklahoma Univ., Norman, OK, NUREG/CR-1183 (Dec 1979).

91. Habercom, G.E., Jr., "Wind Effects; Part 1: Buildings and Bridges (Citations from the Engineering Index Data Base)," National Technical Information Service, Springfield, VA (Dec 1979).

92. Habercom, G.E., Jr., "Wind Effects; Part 1: Buildings and Bridges (Citations from NTIS Data Base)," National Technical Information Service, Springfield, VA (Dec 1979).

93. Petre, A. and Sofronie, R., "Aeroelastic Stability of Suspension Bridges," Res. Roumaine Sci. Tech. Mecanique, 24 (5), pp 819-832 (Sept/Oct 1979).

94. Beynet, P.A., Berman, M.Y., and Von Ashwege, J.T., "Motion, Fatigue and the Reliability Characteristics of a Vertically Moored Platform," J. Pet. Tech., 31 (3), pp 267-274 (Mar 1979).

95. Niemann, H.J. and Ruhwedel, J., "Full Scale and Model Test on Wind-Induced, Static and Dynamic Stresses in Cooling Tower Shells," Engrg. Struc., 2 (2), pp 81-89 (Apr 1980).

96. Simonian, S.S., "System Identification in Structural Dynamics; An Application to Wind Force Estimation," Ph.D. Thesis, Univ. California, Los Angeles (1979).

97. Sidarous, J.F.Y., "Analytical Methodology for Dynamic Building Response to Wind Loading," Ph.D. Thesis, Colorado State Univ. (1979).

98. Griffin, O.M., "Vortex-Excited Cross-Flow Vibrations of a Single Cylindrical Tube," J. Pressure Vessel Tech., Trans. ASME, 102 (2), pp 158-166 (May 1980).

99. Chen, S.S., "Cross-Flow Induced Instabilities of Circular Cylinders," Shock Vib. Dig., 12 (5), pp 21-31 (May 1980).

100. Mu, D., "Dynamic Studies of Cable-Stayed Bridges," Ph.D. Thesis, Brigham Young Univ. (1980).

101. Hagedorn, P., "A Simple Mathematical Model for Calculation of Wind-Excited Vibrations of High-Voltage Lines with Dampers," Ing. Arch., 49 (3/4), pp 161-177 (1980) (in German).

102. Spanos, P.T.D. and Chen, T.W., "Response of a Dynamic System to Flow-Induced Load," Intl. J. Nonlin. Mech., 15 (2), pp 115-126 (1980).

103. Cevallos-Candau, P.J., "The Commonality of Earthquake and Wind Analysis," Ph.D. Thesis, Univ. Illinois at Urbana-Champaign (1980); also published as Rept. No. SER-472, UILU-ENG-80-2002, NSF/RA-800022.

104. Kennedy, M. and Vandiver, J.K., "A Random Vibration Model for Cable Strumming Prediction," Dept. Ocean Engrg., Mass. Inst. Tech., Cambridge, AD-A083 774/0 (1979).

105. Tsui, Y.T. and Tsui, C.C., "Two Dimensional Stability Analysis of Two Coupled Conductors with One in the Wake of the Other," J. Sound Vib., 69 (3), pp 361-394 (Apr 1980).

106. Smith, I.J., "Wind Induced Dynamic Response of the Wye Bridge," Engrg. Struc., 2 (4), pp 202-208 (Oct 1980).

107. Arzoumanidis, S.G., "Finite Element Analysis of Suspension Bridges," Ph.D. Thesis, Columbia Univ. (1980).

108. Singh, H., "Nonstationary Random Response of Structural Systems to Aerodynamic Wind Forces," Ph.D. Thesis, Wayne State Univ. (1980).

109. Van Nunen, J.W.G. and Persoon, A.J., "Investigation of the Vibrational Behaviour of a Cable-Stayed Bridge under Wind Loads," Natl. Aerospace Lab., Amsterdam, The Netherlands, Rept. No. NLR-MP-79004-U (Feb 1979).

110. Walker, S. and Brazier, S.G., "Vortex Shedding Forces and the Fatigue Analysis of Offshore Structures," Intl. Conf. Recent Adv. Struc. Dynam., Univ. Southampton, UK, 1, pp 285-304 (July 1980).

111. Nakamura, Y., "Galloping of Bundled Power Line Conductors," J. Sound Vib., 73 (3), pp 363-377 (Dec 1980).

112. Hagedorn, P. and Schafer, B., "On Non-Linear Free Vibrations of an Elastic Cable," Intl. J. Nonlin. Mech., 15 (4/5), pp 333-340 (1980).

113. Wedig, W., "Stochastic Vibrations of Slim Masts Induced by Turbulent Flows - Modal and Integral Covariance Methods in Hybrid Systems," Intl. Conf. Recent Adv. Struc. Dynam., Univ. Southampton, UK, 1, pp 131-146 (July 1980).

114. Johns, D.J., Milsted, M.G., Bradshaw, P., and Ogendo, J.E.W., "Vibration Models of Steel Chimneys with Added Damping," Intl. Conf. Recent Adv. Struc. Dynam., Univ. Southampton, UK, 1, pp 305-314 (July 1980).

115. Lew, H.S., "Wind and Seismic Effects," Proc. 10th Joint Panel Conf. U.S. - Japan Coop. Program Natural Res., Gaithersburg, MD, Natl. Bureau Stds. Rept. No. NBS-SP-560 (Oct 1980).

116. Dubey, R.N. and Sahay, C., "Vibration of Overhead Transmission Lines III," Shock Vib. Dig., 12 (12), pp 11-14 (Dec 1980).

117. Sigbjornsson, R. and Hjorth-Hansen, E., "Along-Wind Response of Suspension Bridges with Special Reference to Stiffening by Horizontal Cables," Engrg. Struc., 3 (1), pp 27-37 (Jan 1981).

118. Pettigrew, M.J., "Flow-Induced Vibration Analysis of Nuclear Components," Chalk River Nuclear Labs., Atomic Energy of Canada, Ltd., Ontario, Rept. No. ONF-7806125-11 (Aug 1978).

119. Washizu, K., Ohya, A., Otsuki, Y., and Fujii, K., "Aeroelastic Instability of Rectangular Cylinders in a Torsional Mode due to a Transverse Wind," J. Sound Vib., 72 (4), pp 507-521 (Oct 1980).

120. Knisely, C.W., "An Experimental Investigation of Low Frequency Self-Modulation of Incompressible Impinging Cavity Shear Layers," Ph.D. Thesis, Lehigh Univ. (1980).

121. Kareem, A., "Wind Induced Torsional Loads on Structures," Engrg. Struc., 3 (2), pp 85-86 (Apr 1981).

122. Neuerburg, W., "Measurements of Wind and Deformation on a High Radio Tower; Part 1: Introduction," Techn. Messen-ATM, 48 (3), pp 101-106 (Mar 1981) (in German).

123. Matheson, M.J. and Holmes, J.D., "Simulation of the Dynamic Response of Transmission Lines in Strong Winds," Engrg. Struc., 3 (2), pp 105-110 (Apr 1981).

124. Yang, J.N. and Lin, Y.K., "Along-Wind Motion of Multi-Storey Building," ASCE J. Engrg. Mech. Div., 107 (2), pp 295-307 (Apr 1981).

125. Kwok, K.C.S. and Melbourne, W.H., "Wind Induced Lock-In Excitation of Tall Structures," ASCE J. Struc. Div., 107 (1), pp 57-72 (Jan 1981).

126. Martin, W.W., Currie, I.G., and Naudascher, E., "Streamwise Oscillations of Cylinders," ASCE J. Engrg. Mech. Div., 107 (3), pp 589-607 (June 1981).

127. Boonstra, H., "Analysis of Full-Scale Wind Forces on a Semi-submersible Platform Using Operators' Data," J. Pet. Tech., 32 (5), pp 771-776 (May 1980).

128. Farell, C., "Flow Around Fixed Circular Cylinders: Fluctuating Loads," ASCE J. Engrg. Mech. Div., 107 (3), pp 565-588 (June 1981).

129. Foutch, D.A. and Safak, E., "Torsional Vibration of Along-Wind Excited Structures," ASCE J. Engrg. Mech. Div., 107 (2), pp 323-337 (Apr 1981).

130. Neuerburg, W., "Measurements of Wind and Deformation on a High Radio Tower; Part 2: Instruments to Measure the Tower-Deformation and the Free-Streaming Wind," Techn. Messen-ATM, 48 (4), pp 139-145 (Apr 1981) (in German).

131. Safak, E., "Vibration of Buildings under Random Wind Loads," Ph.D. Thesis, Univ. Illinois (1980).

132. Hall, S.A., "Vortex-Induced Vibrations of Structures," Ph.D. Thesis, California Inst. Tech. (1981).

133. Wilkinson, R.H., "Fluctuating Pressures on an Oscillating Square Prism," Aeronaut. Quart., 32 (2), pp 97-110 (May 1981).

134. Simiu, E. and Filliben, J.J., "Wind Direction Effects on Cladding and Structural Loads," Engrg. Struc., 3 (3), pp 181-186 (July 1981).

135. Mortelmans, F.K.E.C., de Roeck, G.P.J.M., and Van Gemert, D.A., "Approximate Method for Lateral Load Analysis of High Rise Buildings," ASCE J. Struc. Div., 107 (ST8), pp 1589-1610 (Aug 1981).

136. Neuerburg, W., "Measurements of Wind and Deformation on a High Radio Tower, Part 3: Measurement," Techn. Messen-ATM, 48 (7/8), pp 275-280 (July/Aug 1981) (in German).

137. Fleischmann, S.T. and Sallett, D.W., "Vortex Shedding from Cylinders and the Resulting Unsteady Forces and Flow Phenomenon; Part 1," Shock Vib. Dig., 13 (11), pp 9-22 (Nov 1981).

138. Fleischmann, S.T. and Sallett, D.W., "Vortex Shedding from Cylinders and the Resulting Unsteady Forces and Flow Phenomenon; Part II," Shock Vib. Dig., 13 (12), pp 15-24 (Dec 1981).

139. Barnaud, G. and Gandemar, J., "Dynamic Simulation of the Atmospheric Boundary Layer at a Model Scale of 1/250," J. Ind. Aero., 4 (1), pp 35-41 (1979).

140. Irwin, H.P.A.H., "Centre of Rotation for Torsional Vibration of Bridges," J. Ind. Aero., 4 (2), pp 123-132 (1979).

141. Cook, N.J. and Mayne, J.R., "A Novel Working Approach to the Assessment of Wind Loads for Equivalent-Static Design," J. Ind. Aero., 4 (2), pp 149-164 (1979).

142. Parkinson, G.V. and Sullivan, P.P., "Galloping Response of Towers," J. Ind. Aero., 4 (3 + 4), pp 253-260 (1979).

143. Mahrenholtz, O. and Bardowicks, A., "Aeroelastic Problems at Masts and Chimneys," J. Ind. Aero., 4 (3 + 4), pp 261-272 (1979).

144. Panggabean, H. and Reichmann, K.H., "Two Dimensional Response of Tower-Like Structures Under Wind Load and Evaluation of Thermal Load Due to Solar Radiation," J. Ind. Aero., 4 (3 + 4), pp 273-294 (1979).

145. Kramer, C., Gerhardt, H.J., and Kuster, H.W., "On the Wind-Loading Mechanism of Roofing Elements," J. Ind. Aero., 4 (3 + 4), pp 415-427 (1979).

146. Konig, G., Zilch, K. and Lappas, G., "Wind Loading of Shipyard Gantry Cranes - Full Scale Measurements," J. Ind. Aero., 4 (3 + 4), pp 429-435 (1979).

147. Mukhopadhyay, V., "The Galloping Oscillations of a Cable of Square Section Suspended in a Smooth Wind Flow," J. Ind. Aero., 5 (1 + 2), pp 35-51 (1979).

148. Greenway, M.E., "An Analytical Approach to Wind Velocity Gust Factors," J. Ind. Aero., 5 (1 + 2), pp 61-91 (1979).

149. Mayne, J.R., "The Estimation of Extreme Winds," J. Ind. Aero., 5 (1 + 2), pp 109-137 (1979).

150. Olmer, J., "Methods of Vibration Measurement of Tall Structures," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 39-48 (1980).

151. Wong, H.Y., "Vortex-Induced Wake Buffeting and Its Suppression," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 49-57 (1980).

152. Zdravkovich, M.M., "Aerodynamics of Two Parallel Circular Cylinders of Finite Height at Simulated High Reynolds Numbers," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 59-71 (1980).

153. Melbourne, W.H., "Comparison of Measurements on the CAARC Standard Tall Building Model in Simulated Model Wind Flows," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 73-88 (1980).

154. Hazelwood, R.A., "Principles of Wind Loading on Tiled Roofs and Their Application in the British Standard BS 5534," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 113-124 (1980).

155. Cook, N.J. and Mayne, J.R., "A Refined Working Approach to the Assessment of Wind Loads for Equivalent Static Design," J. Wind Engrg. Ind. Aero., 6 (1 + 2), pp 125-137 (1980).

156. Dye, R.C.F., "Model Studies of the Wind-Induced Oscillations of a Hexagonal Section Boom Having Tapered End-Portions," J. Wind Engrg. Ind. Aero., 6 (3 + 4), pp 327-334 (1980).

157. Komatsu, S. and Kobayashi, H., "Vortex-Induced Oscillation of Bluff Cylinders," J. Wind Engrg. Ind. Aero., 6 (3 + 4), pp 335-362 (1980).

158. Hanenkamp, W. and Hammer, W., "Transverse Vibration Behaviour of Cylinders in Line," J. Wind Engrg. Ind. Aero., 7 (1), pp 37-53 (1981).

159. Zdravkovich, M.M., "Review and Classification of Various Aerodynamic and Hydrodynamic Means for Suppressing Vortex Shedding," J. Wind Engrg. Ind. Aero., 7 (2), pp 145-189 (1981).

160. Foutch, D.A. and Safak, E., "Torsional Vibration of Wind-Excited Symmetrical Structures," J. Wind Engrg. Ind. Aero., 7 (2), pp 191-201 (1981).

161. Rowbottom, M.D., "The Effect of an Added Mass on the Galloping of an Overhead Line," J. Sound Vib., 63 (2), pp 310-313 (Mar 1979).

162. Johns, D.J., Comments on "On Ovalling Oscillations of Cylindrical Shells in Cross Flow," J. Sound Vib., 67 (3), pp 432-433 (Dec 1979).

163. Dowell, E.H., "Non-Linear Oscillator Models in Bluff Body Aeroelasticity," J. Sound Vib., 75 (2), pp 251-264 (Mar 1981).

164. Rowbottam, M.D., "The Optimization of Mechanical Dampers to Control Self-Excited Galloping Oscillations," J. Sound Vib., 75 (4), pp 559-576 (Apr 1981).

165. Iwan, W.D., "The Vortex-Induced Oscillations of Non-Uniform Structural Systems," J. Sound Vib., 79 (2), pp 291-301 (Nov 1981).

166. Nelson, R.L., "Analyses of Cooling Tower Dynamics," J. Sound Vib., 79 (4), pp 501-518 (Dec 1981).

167. Tesar, A., "Aeroelastic Response of Transporter Shell Bridges in Smooth Air Flow," ACTA Technica CSAV, 1, pp 19-46 (1979).

168. Johns, D.J. and Skordilis, G., "Vortex Excitation by Transverse Flow of Simply-Supported Tubes Containing Fluids," ASME Conf. Flow-Induced Vib., San Francisco, pp 11-18 (June 1979).

169. "Masts and Towers for Radio and Television," Intl. Symp., Intl. Assoc. Shell Spatial Struc., Bratislava, Czechoslovakia (Aug 31 - Sept 4, 1981).

170. Johns, D.J. and Masters, R.H., "Vibration Response to Wind of Two In-Line Circular Cylinders for Various Wind Approach Angles and Speeds," Proc. Inst. Acoust. Spring Conf., Univ. Newcastle-upon-Tyne, UK, pp 155-158 (Apr 1981).

171. Naudascher, E. (Ed.), Flow Induced Structural Vibrations, Springer-Verlag (1974).

172. Dowell, E.H., Curtiss, H.C., Jr., Scanlan, E.H., and Sisto, F., A Modern Course in Aeroelasticity, Sijthoff and Noordhoff, The Netherlands (1978).

173. Sachs, P., Wind Forces in Engineering, 2nd Ed., Pergamon Press (1978).

174. Simiu, E. and Scanlan, R.H., Wind Effects on Structures - An Introduction to Wind Engineering, J. Wiley and Sons (1978).

175. Scruton, C., An Introduction to Wind Effects on Structures, Oxford Univ. Press, UK (1981).

176. Naudascher, E. and Rockwell, D. (Eds.), Practical Experiences with Flow-Induced Vibrations, Springer-Verlag (1980).

177. "Wind Engineering in the Eighties," Proc. Const. Indus. Res. Inform. Assoc. Conf., London, UK (Nov 1980).

178. Cermak, J., Proc. Fifth Intl. Conf. on Wind Engineering, Colorado State Univ. (July, 1979), Pergamon Press (1980).

# BOOK REVIEWS

## FLOW-INDUCED HEAT EXCHANGER TUBE VIBRATION

J.M. Chenoweth, editor
ASME Publ. HTD - Vol. 9
New York, NY, 1980

Heat exchanger problems caused by flow-induced vibration are of concern to designers and operators of heat exchangers. Flow-induced vibration is now as important a cause as heat transfer and pressure drop. Mechanical failure of tubes contributes to failure by causing fatigue, tube joint failure, collision damage, and baffle damage.

Induced vibration of any system requires coupling of an elastic structure with an exciting force. In heat exchangers, the exciting force is the flow of the shellside fluid; the tube bundle is the elastic system. The exciting forces vibrate randomly and are a direct consequence of such factors as flow rate and geometry. If the exciting frequencies induced by flow of the shellside medium coincide with the natural frequencies of the tubes, resonance occurs; the induced stresses can then become intolerable, and failure can occur. The most difficult aspects of shellside fluid-induced exciting forces are identification and composition. Shellside flow does not follow a simple path but is subject to changes in direction as well as acceleration, deceleration, and obstructions. The flow can be either perpendicular to the tubes (cross flow), axially along the tubes (parallel flow), or at any angle between.

The important flow phenomena in cross flow are:

- vortex shedding - flow across the tube causes a series of vortices in the downstream wake that tend to alternately separate from the opposite sides of the tube

- turbulent buffeting - flow due to extremely turbulent flow of the shellside fluid. It contains a vast spectrum of frequencies centered about a dominant frequency. The latter changes with alteration of cross-flow velocity.

- Fluidelastic whirling - results from tubes vibrating in an orbital motion due to flow across the tube. This flow induces a combination of lift and drag displacements of the tubes at their natural frequencies.

- axial or parallel flow eddy formation - results when a heat exchanger contains long unsupported tube spans. High axial flows occur in narrow shellside flow passages.

The seven papers in this monograph describe the state of the art of flow-induced vibration. Both analytical and experimental studies are considered; practical experiences with operational heat exchangers are given.

The first paper, on fluidelastic stability, describes experimental procedures for a number of industrially significant tube bundle arrangements. The author compares his results with those reported in the open literature. The author states that further research is required to understand the mechanism of fluidelastic instability.

The second paper has to do with fretting studies of heat exchanger tubes. Failures can be costly in terms of power station outages and repairs. The author describes a number of experimental results including temperature influences, material combination, tube/support clearances, and fretting tube wear. Additional fretting wear information and impact force analyses are required.

The third paper recognizes turbulent buffeting as a major source of tube vibration and presents information on fluctuating lift and drag forces for tubes in cross flow. Experimental results provide interesting insight into the role of turbulent eddy on fluctuating lift. Strouhal lift forces are given as a function of the active span; another relationship occurs when the turbulent eddy scale is less than the tube diameter.

In the reviewer's estimation, their contribution merits further study to acquire an understanding of scale relations.

The fourth paper presents a series of experimental studies that point out the influence of seal strips close to the shell of a heat exchanger whose prime function is to prevent the passage of fluid between bundle and shell. Experimental studies show the influence of seal strips on the onset of fluidelastic instability. The author concludes that a thorough analysis must include a study of mode shapes and variaton in flow velocity.

The fifth paper describes the practical experience of a large utility where flow-induced vibration in heat exchangers was an expensive problem. The authors describe the development of a practical approach to analysis, specification, and acceptance.

The sixth paper describes a method whereby vibro-acoustic signals from an accelerometer mounted externally on a shell are used to detect tube impacting on an operational heat exchanger prior to failure. The reviewer believes that acoustic emission techniques would supplement this experimental procedure.

The concluding paper examines the relationship of the parameters involved in damping actual tube bundles. Advanced digital analysis techniques involve separating closely-spaced first-mode frequencies and resolving response peaks. This accurate method is used to determine the very small amount of damping in a model tube array close to fluidelastic instability.

In summary, this is an excellent compact volume, but the reviewer would have liked additional papers. This volume is recommended to those individuals interested in flow-induced vibration in heat exchangers.

H. Saunders
General Electric Company
Building 41, Room 307
Schenectady, NY 12345

## COMPUTATIONAL METHODS FOR OFF-SHORE STRUCTURES

H. Armen and S. Stiansen, editors
ASME Publ. AMD - Vol. 37
New York, NY, 1980, 151 pages

Offshore structures require computational methods to link traditional designs and tests. This dynamic analysis involves the random nature of the imposed environments on the offshore structure and influences its design. Despite the uncertainties of precisely identifying random imposed forces, analysts are continuously developing tools to predict the dynamic response of offshore structures. These generally operate in high risk situations that present a constant threat of catastrophic failure. The basic analysis includes a combination of the following:

- hydronamic loading and added mass
- motion of the offshore structure
- structural response that includes fluid-structure interaction

Comprehensive structural analysis includes a unified fluid-structure system and, in general, utilizes finite elements to formulate a mathematical model of the structure. This symposium contains 14 papers on the computational procedures employed in the design of offshore structures.

The initial paper describes the use of an in-house finite element (FE) program called TRAINS to compute the response of a submerged shell structure subjected to a transient acoustic wave. TRAINS employs a clever scheme for decoupling the motion of a dynamically loaded submerged structure and the surrounding fluid. An infinitely long steel shell submerged in water and impinged upon by a plane shock wave is the subject of the analysis. The solution compares favorably with the exact analytical method.

The second paper considers the application of boundary integral methods to hydronamic force calculations. The authors consider structural flexibility; for hydroelastic coupled problems the surface integral method is used for the fluid and the finite element method for the structure. The solution of a rigid cylinder of arbitrary cross section with flexible body

and rigid walls is considered. Further work is required to apply this solution to more complicated problems.

The third paper considers a finite element application of a fluid mass matrix of a structure submerged in an inviscid incompressible fluid. A direct method and an approximate method have been developed to construct the fluid mass matrix for submerged bodies. Further work is required to authenticate the accuracy of the approximate method.

The fourth and fifth papers present methods for analyzing the hydronomic loading of twin semi-submersible hulls and the behavior of flexible hulls in regular seas. The strip theory is used to calculate wave-induced motions and loads for ordinary ships. This theory includes the three-dimensional sink source concepts.

The sixth paper applies the random decrement method (RDM) to the detection of cracks induced in an offshore platform model. RDM analyzes the measured output of a system or model subjected to a random ambient input. Analysis of free vibration response of a signal provides the free vibration response or signature of the mechanical structure. The signal is independent of the input and represents particular structural tests. The investigation can thus detect damage before overall structural integrity is affected. The author describes this powerful method, which has been previously applied in other fields for early crack detection.

The seventh paper focuses on the digital simulation of fatigue damage on offshore structures. The author uses a number of cycle counting methods – i.e., narrow band, rainflow, peak count, and zero crossing -- to analyze random fatigue. The rainflow method is considered the most accurate. A closed form solution for the rainflow method is proposed.

The next two papers consider the response analysis and integrated computational procedure for hydronomic loads on a tension leg platform. Correlation between experimental results and frequency response curves calculated by linear analysis was good except in regimes in which nonlinear responses exist.

The next paper focuses on tension and buckling loads of risers. A linearized version of the mathematical model is used to evaluate critical buckling loads of risers in terms of dimensional design variables.

The eleventh paper discusses a procedure for analyzing tension stiffened marine risers. Wilson's $\phi$ method is used to solve the equations of motion. The analysis can be used to assess stresses and fatigue analyses of marine risers.

Two papers have to do with the buckling of offshore pipelines and the static and dynamic responses of a moored tanker. The finite element analysis of a barge mounted crane subjected to transient wave motion is given. A simplified analysis employing the FE method is used; maximum moments and stresses result from unusually high roll response of the barge and crane at specific frequencies.

This symposium is recommended for those interested in the design of offshore structures.

H. Saunders
General Electric Company
Building 41, Room 307
Schenectady, NY 12345

## BOND GRAPH TECHNIQUES FOR DYNAMIC SYSTEMS IN ENGINEERING AND BIOLOGY

Special Issue of the Journal of the Franklin Institute
Vol. 308, No. 3, Philadelphia, PA, 1979

It is now more than two decades since the notion of unified modeling of energetic dynamic systems with a primitive set of components and junctions was conceived by Paynter. Although in their infancy bond-graph techniques were applied mainly to engineering problems, their subsequent development has been along many different lines, some of which probably could not have been predicted. This special issue of the **Journal of the Franklin Institute** serves as a status report and describes the maturation and growth of the bond-graph field in recent years.

The issue consists of 13 papers that can be generally grouped intc three areas. Six papers describe a wide range of more traditional engineering applications

with electro-mechano-hydraulic energy domains and information processing. Five papers illustrate the rapid growth of the use of bond graphs in modeling biological dynamic systems. These systems include various chemical reactions, ionic transport, heat generation, and photoreception. The two final papers are on theoretical aspects of junction structures and serve to balance somewhat the dominance of the other two areas.

The section on engineering, which will probably be of most interest to readers of the **Shock and Vibration Digest,** contains several interesting papers. Dransfield describes a dynamic model of a 30 kW electrohydraulic system used as a shaker. Tiernego and van Dixhoorn compare two approaches to modeling and simulating a gimbaled three-axis platform; one is based on Lagrangian dynamics and the other on bond graphs. Sahm describes a bond-graph dynamic model of the transient operation of synchronous rotating electrical machinery.

Allen has written on multiport representation of inertias in mechanisms; he explains a technique that produces explicit Lagrange or Hamilton equations for mechanism dynamics suitable for computer solution. Margolis, in a paper on bond-graph fluid line models, interprets the control volume equations for one-dimensional compressible gas dynamics using bond graphs. He shows that such a graph is easily coupled to an overall system model.

Finally, Karnopp, in a paper on bond graphs in control, shows that the same bond graph used to model a system can also be used to derive a complete or reduced order observer as an alternative to measuring all or some state variables. The papers by Sahm, Allen, and Margolis deal directly with vibration-related topics, and should thus be of particular interest to readers of the **Digest.**

The biological section contains little more than an appreciation of the power of bond graphs as an aid to modeling, analysis, and simulation of a variety of biological processes. Plant and Horowitz derive the equations for both isothermal chemical reactions and their coupling to ion transport. In a companion paper by Horowitz, Gracchino, and Horwitz, bond-graph models are used to describe cellular energy conversion mechanisms in brown adipose tissue. In a related paper by Atlan et al bond graphs are used to illustrate the mechanism of interaction of three reticulocyte metabolic processes: potassium efflux through a cell membrane, ATP metabolism, and protein synthesis.

Mikulecky and Thomas present a network thermodynamic method for analysis and simulation of such diverse nonlinear dynamic physiological systems as sodium flow in frog skin and the permeation and metabolism of a chemotherapeutic agent in a cancer cell. Finally, a bond-graph network representation of a model for photoreception is derived by Schnakenberg and Tiedge.

The last two papers by Rosenberg and Moultrie discuss some fundamental issues in multiport junction structures. The papers deal respectively with essential gyrators and reciprocity and with bounds for the number of distinct sets of port variables used to specify the input-output relations in a weighted junction structure. Finally, an up-to-date bibliography compiled by Gebben summarizes most of the work in the field in ten subject-related sections.

This issue as a whole can be compared to an issue that preceded it by seven years in the Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, (94 (3), Sept 1972). The most striking fact revealed from comparative analysis of the accompanying bibliographies, as well as an intervening bibliography (J. Dyn. Syst., Meas. Control, Trans. ASME, 99 (2), pp 143-145, June 1977), is the nearly exponential rise in the number of workers and publications in the bond-graph field. Although the more traditional engineering and biological examples treated in this issue have continued to grow, novel applications have arisen in such diverse and apparently unconnected areas as thermal energy, ecology, and economic and social systems. This leads to the conclusion that the surface has hardly been scratched in terms of number and variety of applications.

Another impression is somewhat disconcerting, however; if the relative number of articles in the issue is taken as representative, only a small fraction is presently concerned with theoretical research. Although it is certainly true that bond graphs must be viewed primarily as an analytical tool with application as their natural focus, healthy development of such an abstract subject would seem to require a

larger proportion of research on fundamental theoretical questions. Statistical confidence is impossible, but it can be said that the proportion of theoretical research has diminished during the last ten years. It is hard to believe that all the theoretical questions have been answered.

When I inspected the bound journal at the Cambridge University library preparatory to writing this review, I found that it opened naturally to the section of biological papers. These had obviously seen a lot of use and were quite worn and dog-eared as a result. If this can be taken as an indicator, perhaps biological application is the area of strong interest and possible growth, at least on the Cambridge campus.

In any case, the volume is highly recommended to those readers who wish to become acquainted with the variety of applications of bond graphs, especially those involved in modeling, analysis, and simulation of vibratory systems involving several energy domains.

M. Hubbard
Visiting Professor
Control and Management Systems Division
Cambridge University, UK

# SHORT COURSES

## AUGUST

### RELIABILITY AND LIFE TESTING

Dates: August 2-6, 1982
Place: Los Angeles, California
Objective: To cover the following subjects: Methodologies to improve the reliability of components, equipment and systems; follow their reliability growth; identify the distributions of their times-to-failure; determine their mean life, their reliability, and their failure rate, with their confidence limits at specified confidence levels; various new small-sample-size, short-duration reliability and life tests; non-parametric reliability and life tests; sequential tests for the exponential and binomial cases; tests of comparison for the exponential, Weibull and binomial cases; accelerated life testing; Bayesian life and reliability testing; identification of the appropriate times-to-failure distributions to use and the application of goodness-of-fit tests to distributions fitted to data; probability plotting techniques to find the parameters of the appropriate distributions to use.

Contact: Mr. Robert Rector, Assistant Director - Short Courses, UCLA, 6266 Boelter Hall, Los Angeles, CA 90024 - (213) 825-3496.

### MACHINERY VIBRATION ANALYSIS

Dates: August 17-20, 1982
Place: New Orleans, Louisiana
Dates: November 9-12, 1982
Place: Oak Brook, Illinois
Objective: In this four-day course on practical machinery vibration analysis, savings in production losses and equipment costs through vibration analysis and correction will be stressed. Techniques will be reviewed along with examples and case histories to illustrate their use. Demonstrations of measurement and analysis equipment will be conducted during the course. The course will include lectures on test equipment selection and use, vibration measurement and analysis including the latest information on spectral analysis, balancing, alignment, isolation, and damping. Plant predictive maintenance programs, monitoring equipment and programs, and equipment evaluation are topics included. Specific components and equipment covered in the lectures include gears, bearings (fluid film and antifriction), shafts, couplings, motors, turbines, engines, pumps, compressors, fluid drives, gearboxes, and slow-speed paper rolls.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

### VIBRATION RESPONSE CALCULATIONS FOR REAL ROTORS

Dates: August 24-27, 1982
Place: Heriot-Watt University, UK
Objective: This is an intensive course for engineers involved in the vibration analysis of rotors supported in journal bearings. The course will also be of benefit to professional engineers who are responsible for the commissioning and maintenance of rotating plant. A feature of the course will be on-line computation of the response and stability of rotor bearing systems. This will be reinforced by an outline of the theoretical methods used, and quantitative descriptions of vibration exciting forces. Practical demonstrations of contemporary monitoring equipment by Bently Nevada Ltd. will be included.

Contact: R.D. Brown, Course Director or T.K. Crichton, Course Administrator, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS - Telephone: 031-449-5111.

## SEPTEMBER

### SIMULATION AND ANALYSIS OF COMPLEX MECHANICAL SYSTEMS

Dates: September 6-10, 1982
Place: Northampton, UK
Objective: The goal is to assist participants in be-

coming proficient in the formulation of equations of motion of complex mechanical systems. With this background, the participants will be able to produce efficient algorithms for the simulation of motions and for the determination of constraint and control forces arising in connection with such systems.

Contact: The Open University, Walton Hall, Milton Keynes, MK7 6AA, Telephone: Milton Keynes 653945, Telex: 825061.

**ELEVENTH ADVANCED NOISE AND VIBRATION COURSE**

Dates: September 13-17, 1982
Place: Southampton, UK
Objective: The course is aimed at researchers and development engineers in industry and research establishments, and people in other spheres who are associated with noise and vibration problems. The course, which is designed to refresh and cover the latest theories and techniques, initially deals with fundamentals and common ground and then offers a choice of specialist topics. There are over thirty lectures, including the basic subjects of acoustics, random processes, vibration theory, subjective response and aerodynamic noise, which form the central core of the course. In addition, several specialist applied topics are offered, including aircraft noise, road traffic noise, industrial machinery noise, diesel engine noise, process plant noise and environmental noise and planning.

Contact: Mrs. G. Hyde, ISVR Conference Secretary, The University, Southampton S09 5NH, UK - Telephone - (0) (703) 559122 X 2310/752; Telex - 47661 SOTON UN G.

**RELIABILITY TESTING**

Dates: September 20-24, 1982
Place: Washington, DC
Objective: This course has been designed to enable participants to calculate the failure rates of components and products; determine the early, chance, and wear-out reliability of components and products; determine the parameters of distributions involved in the time-to-failure data of components and products analytically and by probability paper plotting; conduct chi-square and Kolmogorov-Smirnov goodness-of-fit tests to determine the most appropriate distribution to use; determine the confidence limits on the reliability for the exponential, normal, log-normal, Weibull, and binomial cases; determine the operating characteristic curves of components and products; plan, conduct, and analyze the results of sudden death, suspended-items, percent survival, success run, C-rank, and nonparametric tests; plan, conduct, and analyze the results of sequential, Bayesian, and accelerated tests; and plan, conduct, and analyze tests of comparison for exponential, binomial, and Weibull cases.

Contact: Mr. Stod Cordelyou, Deputy Director, Continuing Engineering Education Program, The George Washington University, Washington, DC 20052 - (202) 676-6106; (800) 424-9773; Telex: 64374 (International).

**COMPUTER VIBRATION ANALYSIS**

Dates: September 21-24, 1982
Place: Naperville, Illinois
Objective: The course deals with the role of the digital computer in solving vibration problems that arise in design, development, and fault diagnosis; fracture analysis is covered in depth. Applications of the computer to vibration problems associated with modeling, computation, and data handling are reviewed. Selection and use of hardware and software for computer analysis are discussed. The course begins with a review of vibration theory and a discussion of the types of vibration analysis available. Methods for obtaining and processing the physical data necessary to construct hardware models are described. Readily available and practical short computer programs are summarized, as are such large dynamic programs as NASTRAN, SAP, and ANSYS. Applications of these programs -- including pre-processors and post-processors -- are elaborated. Methods for predicting vibration failures that utilize fracture mechanics and finite element crack models are applied to such practical problems as generator motors. Available time-sharing services and the computer equipment required for such time sharing are discussed. Microcomputer hardware and software are reviewed and their capabilities summarized.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

**SYSTEMATIC APPROACH TO IMPROVING MACHINERY RELIABILITY IN PROCESS PLANTS**

Dates: September 28-30, 1982
Place: Toronto, Ontario
Dates: February 23-25, 1983
Place: San Francisco, California

Objective: This seminar is intended to guide machinery engineers, plant designers, maintenance administrators, and operating management toward results-oriented specifications, selection, design review, installation, commissioning, and post start-up management of major machinery systems for continued reliable operations. Emphasis will be on pumps, compressors, and drivers.

Contact: Sherry Theriot, Professional Seminars International, P.O. Box 156, Orange, TX 77630 - (713) 746-3506.

**TORSIONAL VIBRATIONS**

Dates: September 28-30, 1982
Place: Oak Brook, Illinois

Objective: The course emphasizes methods for diagnosing and solving torsional vibration problems in existing equipment. Methods for controlling and eliminating torsional vibrations during the machinery design process are also described. Examples and case histories are used to illustrate mathematical and experimental techniques. The introductory lectures include a short review of basic torsional vibration concepts and a classification of excitations from various types of machines. A discussion of natural frequencies, mode shapes, critical speeds, and torsional vibration response includes the relationship of these factors to mechanical design and analysis. Such criteria for evaluating torsional vibration as strength and motion are discussed, as is the application of these criteria to solving machine problems; allowable stresses and motions are given. Requirements, sources, and techniques for measuring and calculating parameters for the acquisition of design data are topics for several lectures. Data from blueprints and physical measurements are used to model systems and components for such parameters as stiffness, damping, and mass. Models of physical systems, explicit formulas, and the Holzer method are used to calculate such parameters as natural frequencies and mode shapes. Several lectures are devoted to steady and transient forced vibration responses and include the measurement and analysis of motions and stresses. Techniques involved in premeasurement, calibration of sensors, and actual measurement of forced vibration are discussed and demonstrated. Case histories are used to illustrate what, where, and how to measure and analyze specific torsional vibration problems on such components as pumps, compressors, gearboxes, engines, motors, and couplings. Torsional/lateral interactions in rotors, gearboxes, and pumps are described. Such techniques of vibration control as tuning, reduction of excitation, damping, and isolation are elaborated. Selection of the proper coupling for vibration control and for capability to prevent misalignment is emphasized.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

## OCTOBER

**UNDERWATER ACOUSTICS**

Dates: October 4-8, 1982
Place: State College, Pennsylvania

Objective: The course is designed to provide participants with a broad, comprehensive introduction to underwater acoustics and related topics which will be of immediate practical value; and to provide a foundation for more advanced study of current literature or other specialized courses. Topics presented include underwater sound propagation, sonar concepts, ambient noise and other environment considerations, sonar electronics and signal processing, transducer technology, non-linear acoustics and parametric arrays, target physics, and radiated and self-noise due to turbulent flows and cavitation. Each of the instructors for this course are actively involved in both the theoretical and practical aspects of the material they will present, and will be happy to confer on individual questions or problems.

Contact: Alan D. Stuart, Course Chairman, The Applied Research Laboratory, The Pennsylvania State University, P.O. Box 30, State College, PA 16801 - (814) 865-1397.

**VIBRATION CONTROL**

Dates: October 11-15, 1982

Place: University Park, Pennsylvania

Objective: The seminar emphasizes principles, general approaches and new developments, with the aim of providing participants with efficient tools for dealing with their own practical vibration problems.

Contact: Mary Ann Solic, Pennsylvania State University, 410 Keller Conference Center, University Park, PA 16802 - (814) 865-4591, TWX No: 510-670-3532.

**MAINTAINABILITY AND AVAILABILITY ENGINEERING OF EQUIPMENT AND SYSTEMS**

Dates: October 18-22, 1982

Place: Los Angeles, California

Objective: To cover the following subjects: The equipment reliability, maintainability and availability interrelationships. The design of equipment to maximize their accessibility and minimize their downtime. Determination of equipment downtime, time-to-restore distribution, and mean maintenance man-hours per operating hour; spare parts requirements at a desired confidence level and spares optimization. Preventive maintenance policies and the quantification of the resulting increase in the reliability of maintained equipment. Determination of the optimum preventive maintenance schedule of equipment to minimize their total corrective and preventive maintenance cost. Quantification of reliability and availability of maintained equipment considering their failure and repair rates. Determination of the various steady state availabilities of equipment and systems. The planning, execution, data acquisition, and data analysis of equipment maintainability demonstration tests.

Contact: Mr. Robert Rector, Assistant Director - Short Courses, UCLA, 6266 Boelter Hall, Los Angeles, CA 90024 - (213) 825-3496.

**INTRODUCTION TO RANDOM VIBRATION AND SHOCK TESTING**

Dates: October 18-22, 1982

Place: Boston, Massachusetts

Objective: The course content will emphasize random vibration, which is increasingly being required by such military standards as MIL-STD-810C for qualification and acceptance environmental testing and MIL-STD-781C for reliability demonstration testing. It is also required for 100% production stress screening on many new military electronics and avionics contracts. Quality and reliability engineers, particularly those involved with high-reliability instruments and systems, should have considerable understanding of modern test technology, including vibration and shock testing, measurement, analysis and calibration. They need to interpret test standards. They often witness tests. They need to assure that equipment and personnel are fully qualified. Quality and reliability engineers thus need basic education in resonance and fragility phenomena, in environmental vibration and shock measurement and analysis, also in vibration and shock testing to prove survivability. Equipments and techniques are emphasized, while mathematics and theory are minimized.

Contact: Wayne Tustin, Tustin Institute of Technology, 20-22 East Los Olivos, Santa Barbara, CA 93105 - (805) 682-7171.

# NEWS BRIEFS: news on current and Future Shock and Vibration activities and events

## NOISE-CON 83

### Announcement and Call for Papers

***Quieting the Noise Source*** is the theme of NOISE-CON 83, the Seventh National Noise Conference sponsored by the Institute of Noise Control Engineering. NOISE-CON 83 is cosponsored by the Departments of Mechanical Engineering and Aeronautics and Astronautics at Massachusetts Institute of Technology.

NOISE-CON 83 will be held on March 21-23, 1983 at Massachusetts Institute of Technology in Cambridge, Massachusetts.

The technical program will emphasize physical understanding of noise generation and control of noise at its source. A plenary session on basics of aerodynamic noise and noise generation in valves will open the program. Eleven other sessions are presently planned:

- Fans, Turbines, and Airfoils
- Valves and Orifices
- Printers and Typewriters
- Presses and Forming Machines
- Tires and Rollers
- Burners and Combustors
- Air conditioners and Heaters
- Transformers and Motors
- Mechanisms: Saws, Gears, and Cams
- Source identification and diagnostics
- Other source quieting and structural design

Not included in the scope of the conference will be regulations, barriers, enclosures, community noise, mufflers, and silencers. Each session will consist of invited papers and a limited number of contributed papers, all to be published in the Proceedings.

Contributed papers will be selected by a review of abstracts (maximum of 500 words and up to one figure and five equations, if needed). The deadline for receipt of these abstracts is September 30, 1982.

For those accepted, complete papers will be due promptly by December 17, 1982.

Submit abstracts to the Technical Program Chairman:

Professor Richard H. Lyon
MIT Room 3-366
77 Massachusetts Avenue
Cambridge, MA 02139

For more information on the conference, contact:

NOISE-CON 83
Massachusetts Institute of Technology
Institute Information Services
77 Massachusetts Avenue
Cambridge, MA 02139
(617) 253-1703

## 11TH TURBOMACHINERY SYMPOSIUM '82
### December 14-16, 1982
### Houston, Texas

The Turbomachinery Laboratories of the Department of Mechanical Engineering at Texas A&M University announces its 11th Turbomachinery Symposium to be held December 14-16, 1982 at the Shamrock Hilton Hotel in Houston, Texas.

The Turbomachinery Symposium has been established to serve the user of turbomachinery. The Symposium provides interested persons with the opportunity to learn the applications and principles of various types of turbomachinery, to enable them to keep abreast of the current technology and developments in the field, and to provide an open forum for the attendees to exchange ideas and relate their own experiences. Users, manufacturers, basic design engineers and technicians have the opportunity to share equally in the discussion of the various problem areas. The tutoriums and lectures will also inform the attendees of the latest developments in the area of turbomachinery and other related equipment.

**Tentative Program**

***Lectures:***

- Vibration Monitoring Programs Based on Micro-Computer Data Base
- Face Seals
- Seal Influence on Rotordynamics: Computational and Experimental State-of-the-Art
- Design and Application of Honeycomb and Abradable Seals
- Grouting of Machinery and Structures
- Trip and Throttle Valves for Steam Turbines: Design and Application Considerations
- Upgrading of Existing Steam Turbines for Increased Efficiency
- Overview on the Design and Development of Energy Efficient Turbines
- Application of Bearings to High Speed Machinery Using Rotordynamics Modeling
- Design Life of Parts, Equipment Guarantees
- Lubrication
- On-Line Monitoring Systems for Ethylene Plants
- Torque Couplings
- Burning Alternate Fuels in Gas Turbines
- Factory Performance Testing of Compressors and Turbines
- Small Air Compressors
- Bearing Stability
- Seismic Spectrograph Analysis of Motor Data, Analysis (Diagnostic), Confirmation and Correlation
- Advantages vs. Disadvantages of High Speed Balancing

***Discussions***

- Shop Techniques for Repair and Maintenance of Turbomachinery
- Compressor and Steam Turbine Operation and Maintenance
- Gas Turbine and Driven Equipment
- Large Electric Motors: Mechanical Performance
- Monitoring and Protection of Turbomachinery
- Pumps: Operation and Maintenance

***Tutoriums***

- Hydraulic Fits: Safety Features in Design and Mounting
- Shaft Reclamation and Repair Techniques

***Panel Session:***

- Centrifugal and Axial Compressor Blade Coatings for Performance Enhancement

For further information contact: Dr. Peter E. Jenkins, Director, Turbomachinery Symposium, Turbomachinery Laboratories, Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843 - (713) 845-7417.

## INTERACTION OF NON-NUCLEAR MUNITIONS WITH STRUCTURES

**Announcement and Call for Papers**

The United States Air Force is sponsoring a symposium on The Interaction of Non-Nuclear Munitions with Structures to be held May 9-13, 1983 at the United States Air Force Academy, Colorado Springs, Colorado.

General Subject Areas include:

- Material Behavior
- Constitutive Equations
  - Rock
  - Soil
  - Concrete
- Blast/Structure Interaction
  - Near Field
  - Far Field
  - Soil
  - Air
- Failure Analysis
  - Member (beams, plates, slabs)
  - Structure
- Structural Response
  - Blast
  - Kinetic Energy
  - Methodology
  - Above Ground
  - Below Ground
- Impact and Penetration

For further information contact: Dr. C.A. Ross, P.O. Box 1918, Eglin AFB, Florida 32542 - (904) 882-5614, Autovon 872-5614.

# INFORMATION RESOURCES

## PAVEMENTS AND SOIL TRAFFICABILITY INFORMATION ANALYSIS CENTER (PSTIAC)

### ORIGIN, MISSION AND SCOPE

The PSTIAC was established on 19 April 1966 and is one of four centers located at the Waterways Experiment Station (WES). The PSTIAC provides information in a clearly defined mission-oriented subject area which is of special interest to the Department of the Army and other elements of the DOD. Subjects covered by the Center include flexible and rigid pavements, expedient surfacing, ground flotation, and research in surface vehicle mobility, trafficability, and terrain analysis. This work is directed primarily toward military needs and priority is given to agencies of the DOD and their contractors. An appreciable amount of assistance is provided to mission-oriented work at WES. Services are also available to others in the scientific community, private sector, and industry at large subject to facility and manpower limitations.

### ORGANIZATION OF PSTIAC

The director of PSTIAC is the only full-time employee of the Center. He is responsible for planning, directing, and executing the work of the Center. Technical assistance in answering specific inquiries is provided as needed by a number of experienced engineers and scientists on the staff of the Mobility Systems Division (MSD) and the Pavement Systems Division (PSD) of the Geotechnical Laboratory (GL), and the Environmental Systems Division (ESD) of the Environmental Laboratory (EL), WES. The Technical Information Center (TIC) at WES supports PSTIAC activities in its capacity as a central source of technical information.

Most of the funds for operation of the Center are provided by the US Army Materiel and Readiness Command (DARCOM). Some additional monies are obtained by reimbursement of costs for services.

### INFORMATION SOURCES AND OPERATIONS

The principal purpose of the PSTIAC is to provide the user community with a comprehensive, readily accessible source of current information within the scope of the Center's activities. The Center has access to two principal direct sources of information: index files and bibliographies developed and located at the Center, and information in the library of the TIC at WES.

***PSTIAC microthesaurus.*** One of the first tasks of the Center was the development and publication of a microthesaurus of vehicle mobility, environment, and pavement terms (see "Publications"). This was an important undertaking because the key word terms in the thesaurus are not only basic to the systematic storage and retrieval of literature compiled by PSTIAC and the TIC library but by other organizations and information centers working in the field. The thesaurus has been integrated into a WES microthesaurus covering a larger number of engineering and scientific terms. The PSTIAC microthesaurus follows COSATI guidelines. Each main term is referenced with respect to "use," "use for," "broad," "narrow," and "related" to assist the user in selecting proper key words for indexing and searching literature. Also, each term is coded with the letters, M, E, and P, individually or in combination, to designate usage of the term in subject fields of mobility, environment, and pavements, respectively.

***Report bibliographies.*** Another important undertaking of the Center has been the compilation and publication of bibliographies of WES reports on vehicle mobility, terrain, and pavements, respectively (see "Publications" for listing of reports). The bibliographies include listings of report titles, indexes for subject, personal author, corporate author, geographical region and military base, and report documentation page data including abstracts of the

reports. These bibliographies provide an important source of information in quick-response replies to inquiries by customers of the Center.

***Standards for off-road mobility.*** The Center, in conjunction with the International Society of Terrain-Vehicle Systems (ISTVS), has prepared a set of Standards relevant to off-road mobility. Three sections have been completed to date: Section A - Glossary of Terrain-Vehicle Terms; Section B - Soil-Test Devices Associated with Soil-Vehicle Tests; and Section C - Abbreviations and Symbols. The Standards have been published in the Journal of Terramechanics, 1977, Volume 14, No. 3, pages 153-182, Pergamon Press. The Standards were adapted by ISTVS in 1978 and are used by all researchers in the field of vehicle mobility.

***Indexes.*** Published indexes from various scientific organizations and indexes compiled from technical periodicals relating to vehicle mobility and terrain provide an important source of information. Some of the more important indexes on file in the Center, and the period of record of each, are:

- Samarbetsorganisationen för Fordon-Markforskning (SFM) Literature Index, 1968-1978 (includes abstracts of articles on mobility and terrain).
- The Motor Industry Research Association (MIRA) Automobile Abstracts, 1955-1981.
- Society of Automotive Engineers (SAE) Transactions, Index Abstracts, 1966-1978.
- Cumulative Index of SAE Technical Papers, 1965-1978.
- Author and Subject Index to the Soil Science Society of America Proceedings, 1947-1971.
- Author and Subject Index to the Soil Science Society of America Journal, 1945, 1972-1981.
- Comprehensive Index of American Society of Agricultural Engineers (ASCE) Publications, 1971-1980.
- Author and Subject Index of the Shock and Vibration Digest, 1975-1981.
- Author and Subject Index of Tire Science and Technology, 1973-1978.
- Index of Material Published in Soviet Soil Science, 1972-1979.
- Index of Authors, Titles, and Keywords of The Military Engineer, 1968-1979.
- Author and Subect Index of GEO Abstracts, Landforms and the Quaternary, 1972-1981.
- Armor Magazine Title and Author Index, 1974, 1980.
- Vehicle System Dynamics Subject Index, 1972-1973, 1976-1977.

***TIC Library.*** PSTIAC draws heavily on the TIC library at WES for its information. About 50,000 items relating to subjects of interest to PSTIAC including books, technical reports, periodicals, reprints, and three types of microforms are on file. Indexes in the library of some relevance to PSTIAC include Engineering Index, Applied Science and Technology Index, British Technology Index, the Environment Index, Monthly Catalog of US Government Publications, and Government Reports Index. The Center has ready access to the library catalog, which is the primary tool for the retrieval and dissemination of information for WES and the Corps of Engineers. In addition, it has catalogs from several other libraries and information centers in either card or book form. Items of relevance include US Geological Survey Library, Engineering Societies Library, John Crerar Library in Chicago, American Geophysical Society, and the Library of Congress (including Library of Congress Catalog of Printed Cards, National Union Catalog of the Library of Congress, Library of Congress Author Catalog, and Library of Congress Catalog, Books (Subjects)).

A remote on-line terminal in the WES library links the Center to the Defense Research and Development Test and Evaluation On-Line System at DTIC. Information from the Technical Report Data Bank, the Work Unit Data Bank, and Research and Development Program Planning Data Bank can be displayed on the terminal screen and a printout of the information on the screen can be obtained through the console. Operators can acquire on-the-spot information while the requester observes the structuring of the search. An additional terminal in the library is available for searches on-line, from Lockheed Information Systems DIALOG, which provides access to more than 50 machine computer-readable data bases.

## SERVICES AND PUBLICATIONS

PSTIAC serves its user community through personal technical advisory service working in close coordina-

tion with the staff of the WES TIC. Information is provided by mail, telephone, interoffice communication, or in person.

***Technical inquiries and requests for publications.*** Requests for assistance are given high priority and quick response. Requests for general technical information or data, bibliographies or abstracts, information on vehicles and test equipment, and sources of specific information are handled by the Center. Highly technical questions that cannot be answered by the Center are referred to engineering or scientific specialists at WES or others in the scientific community. Requests for publications for loan are referred to the library. Requests for publications for retention are referred to the Publications Distribution Section at WES or to private or other governmental agencies that distribute publications. For example, requests from DOD users for technical publications (with an AD number) not available at WES are referred to the Defense Technical Information Center (DTIC); other requests are referred to the National Technical Information Service (NTIS).

***Current awareness program.*** The Center, working in close coordination with the library, circulates current bibliographic citations, abstracts, and occasionally copies of pertinent papers. Information is obtained from technical journals, proceedings of professional societies, technical abstract services, scientific periodicals, and DTIC profile listings. Recipients are in-house engineers and scientists and some outside specialists who have specific needs for this information.

***Special studies and activities.*** In addition to its other activities, the Center participates in planning national and international meetings of professional societies and WES laboratory symposia and workshops in pavements and mobility. Financial assistance is given when available and appropriate. Facilities and personnel are also available for conducting state-of-the-art surveys. Technical assistance is provided to foreign military personnel on tours of duty in this country.

***Service charges.*** No charges are made for letter, telephone, or in-person inquiries that normally require less than one-half day to answer. Jobs requiring more time are charged on a cost-reimbursable basis.

***Publications.*** Reports published by the Center include:

- PSTIAC-1, "Microthesaurus of Vehicle Mobility, Environment, and Pavement Terms," April 1975 (AD A011 269).
- PSTIAC-2, "Bibliography of Papers Presented at Meetings or in Technical Journals on Studies of the Mobility and Environmental Systems Laboratory," by Marvin P. Meyer, November 1975 (AD A018 290).
- PSTIAC-3, "A Bibliography with Abstracts of U.S. Army Engineer Waterways Experiment Station Publications Related to Vehicle Mobility," by Marvin P. Meyer, August 1976 (AD A031 524).
- PSTIAC-4, "A Bibliography with Abstracts of U.S. Army Engineer Waterways Experiment Station Publications Related to Terrain," by Marvin P. Meyer, June 1977 (AD A043 789).
- PSTIAC-5, "A Bibliography with Abstracts of U.S. Army Engineer Waterways Experiment Station Publications Related to Pavements:"
  - -- "Volume I: List of Reports and Indexes," by M.P. Meyer and Virginia Dale, August 1977 (AD A045 024).
  - -- "Volume II: Report Documentation Page Data, Part 1: Bulletins, Instruction Reports, Miscellaneous Papers," by M.P. Meyer and Virginia Dale, August 1977 (AD A045 025).
  - -- "Volume II: Report Documentation Page Data, Part 2: Technical Memoranda, Technical Reports, Pavements and Soil Trafficability Information Analysis Center Reports, Contract Reports," by M.P. Meyer and Virginia Dale, August 1977 (AD A045 026).

## POINTS OF CONTACT FOR SERVICES

***Address:***

Commander and Director
U.S. Army Engineer Waterways Experiment Station
Attention: PSTIAC (Mr. Meyer)
P.O. Box 631
Vicksburg, MS 39180

***Director:*** Mr. Marvin P. Meyer
(601) 634-2795

***Service Point of Contact:***

Technical/Bibliographical Inquiries -- Trafficability, Mobility, Terrain
Mr. Marvin P. Meyer, (601) 634-2795

Technical/Bibliographical Inquiries -- Pavements
Harry H. Ulery, Jr., (601) 634-2209

Computerized Data Base/Library
James A. Sherlock, (601) 634-2533

# ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, VA 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM), 313 N. Fir St., Ann Arbor, MI; U.S. Patents from the Commissioner of Patents, Washington, DC 20231. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

## ABSTRACT CONTENTS


**MECHANICAL SYSTEMS . . . . 55**

Rotating Machines . . . . . 55
Reciprocating Machines . . . 58
Metal Working and Forming . . . . . 59

**STRUCTURAL SYSTEMS . . . . 60**

Bridges . . . . . 60
Buildings . . . . . 60
Towers . . . . . 62
Foundations . . . . . 62
Harbors and Dams . . . . . 63
Power Plants . . . . . 63
Off-shore Structures . . . . . 65

**VEHICLE SYSTEMS . . . . . 66**

Ground Vehicles . . . . . 66
Ships . . . . . 67
Aircraft . . . . . 67
Missiles and Spacecraft . . . . 71

**BIOLOGICAL SYSTEMS . . . . . 71**

Human . . . . . 71

**MECHANICAL COMPONENTS . 72**

Absorbers and Isolators . . . 72
Blades . . . . . 73
Bearings . . . . . 73
Gears . . . . . 75
Fasteners . . . . . 75
Valves . . . . . 76
Seals . . . . . 76

**STRUCTURAL COMPONENTS . 77**

Strings and Ropes . . . . . 77
Cables . . . . . 77
Bars and Rods . . . . . 78
Beams . . . . . 79
Cylinders . . . . . 80
Columns . . . . . 81
Membranes, Films, and Webs . . . . . 81
Panels . . . . . 81
Plates . . . . . 82
Shells . . . . . 85
Pipes and Tubes . . . . . 85
Ducts . . . . . 89
Building Components . . . . . 89

**DYNAMIC ENVIRONMENT . . . 91**

Acoustic Excitation . . . . . 91
Shock Excitation . . . . . 94
Vibration Excitation . . . . . 95

**MECHANICAL PROPERTIES . . 97**

Damping . . . . . 97
Fatigue . . . . . 98
Elasticity and Plasticity . . 102

**EXPERIMENTATION . . . . . 102**

Measurement and Analysis . . . . . 102
Dynamic Tests . . . . . 105
Scaling and Modeling . . . . 105
Diagnostics . . . . . 105
Monitoring . . . . . 105

**ANALYSIS AND DESIGN . . . 106**

Analytical Methods . . . . . 106
Modeling Techniques . . . . 110
Numerical Methods . . . . . 111
Parameter Identification . . 111
Design Techniques . . . . . 112
Computer Programs . . . . . 112

**GENERAL TOPICS . . . . . 113**

Conference Proceedings . . 113
Criteria, Standards, and Specifications . . . . . 114
Bibliographies . . . . . 114

# MECHANICAL SYSTEMS

## ROTATING MACHINES

(Also see No. 1408)

**82-1336**

**Coupled Rotor/Airframe Vibration Analysis by a Combined Harmonic-Balance, Impedance-Matching Method**

T.-K. Hsu

Ph.D. Thesis, Washington Univ., 174 pp (1981) UM 8201881

Key Words: Rotors, Helicopters, Airframes, Harmonic balance method, Mechanical impedance

A coupled rotor/airframe vibration analysis is performed by the matching of rotor and fuselage impedances. The rotor impedance for b blades is calculated from the periodic-coefficient equations of a single blade in forward flight. Three flapping modes are included, and the equation is solved by harmonic balance. The fuselage impedance, including structural damping, is calculated for 3 rigid-body and 3 elastic modes in plunge, role, and pitch. The results show that the effect of hub motions on rotor loads is greatest for relatively stiff rotors, and is not well-approximated by lumped-mass or purely inertial rotor models.

**82-1337**

**Stability Analysis of Multi-Span Rotor System and Its Application (Part III, Theory of Multi-Span Rotor and Its Experiment)**

T. Iwatsubo, M. Okaue, and R. Kawai

The Faculty of Engrg., Kobe Univ., Rokko, Nada, Kobe, Japan, Bull. JSME, 25 (199), pp 88-94 (Jan 1982) 6 figs, 4 tables, 4 refs

Key Words: Rotors, Bearings, Stability

The theory of Part 1 for the two-bearing rotor system is extended to a multi-bearing rotor system by using the transfer matrix method. The extended theory is applied to the three-bearing rotor system and is experimentally proved. The effect of bearing pressure on the stability of the rotor system is tested for the above rotor system and compared with theoretical results. It is concluded that the proposed theory is useful in diagnosing the unstable rotor system and in improving the bearings.

**82-1338**

**Subsynchronous Vibrations of Rotor Systems**

S.B. Malanoski

Mechanical Technology, Inc., 968 Albany-Shaker Rd., Latham, NY 12110, Shock Vib. Dig., 14 (3), pp 15-21 (Mar 1982) 86 refs

Key Words: Rotors, Subsynchronous vibration, Reviews

This article is a review of the literature published from 1979 through 1981, but especially in 1980, on subsynchronous vibration of rotor systems. Experimental and analytical studies cover various mechanisms for this instability that can be introduced by hydrodynamic bearings, high pressure fluid seals, labyrinth seals, and working fluids. Papers on practical experience for stability control are cited.

**82-1339**

**Effects of Three-Lobe Bearing Geometries on Rigid-Rotor Stability**

R.D. Flack and R.F. Lanes

Univ. of Virginia, Charlottesville, VA 22901, ASLE Trans., 25 (2), pp 221-228 (Apr 1982) 14 figs, 1 table, 15 refs

Key Words: Rotors, Rigid rotors, Stability, Bearings, Geometric effects

The stability of a rigid rotor mounted in three-lobe bearings is theoretically studied for which the preload factor, offset factor, and load orientation are systematically varied. Rigid-rotor stability maps are presented. Results indicate that bearings with offset factors of 0.1 or less and moderate preload factors are often more stable than those with larger offset factors. Results also indicate that, for a given preload and load orientation, a particular offset factor exists which produces minimum stability (such bearing geometries should be avoided). Finally, increasing the preload factor was found to increase the rigid-rotor stability.

**82-1340**

**Super-Summed-and-Differential Harmonic Oscillations of an Unsymmetrical Shaft and an Unsymmetrical Rotor**

T. Yamamoto, Y. Ishida, T. Ikeda, and H. Suzuki Nagoya Univ., Chikusa-ku, Nagoya, Japan, Bull. JSME, 25 (200), pp 257-264 (Feb 1982) 15 figs, 9 refs

Key Words: Shafts, Harmonic response, Sum and difference frequencies

Super-summed-and-differential harmonic oscillations in rotating shaft systems are studiod theoretically and experimentally. This kind of nonlinear forced oscillation occurred experimentally in the unsymmetrical shaft system carrying a disc and in the unsymmetrical rotor system where the rotor was mounted on a shaft with circular cross section (a round shaft). We have also compared these oscillations with those in the system where a disc is installed on a round shaft. It is concluded theoretically that large unsymmetry of a rotating shaft or a rotor makes it easier for super-summed-and-differential harmonic oscillations to occur in a rotating shaft system. Not only stable stationary oscillations but also unstable ones may occur. The experimental results are consistent qualitatively with the theoretical ones.

## 82-1341
## Q-Factor Analysis of Unbalance Vibration in Rotor-Bearing Systems

O. Matsushita, M. Ida, and K. Kikuchi
Mech. Engrg. Res. Lab. of Hitachi Ltd., 502, Kandatsu-Machi, Tuchiura-Shi, Ibaraki, Japan, Bull. JSME, 25 (200), pp 265-276 (Feb 1982) 14 figs, 4 tables, 8 refs

Key Words: Rotor-bearing systems, Q-factor, Amplitude analysis, Critical speeds

Q-factor is usually a practical means for predicting maximum amplitude at critical speeds. However, it is not accurate in the case of systems with strong gyroscopic effect, large damping coefficients and asymmetric properties in bearing dynamics. In this study these problems are solved through a new definition of the Q-factor. To demonstrate the validity of the method, numerical examples are shown for a 3-disk rotor supported with symmetric and tilting pad type bearings.

## 82-1342
## Critical Speed of Rotor in a Liquid

T. Shimogo and Y. Kazao
Keio Univ., 14-1, Hiyoshi 3-Chome, Kohoku-Ku, Yokohama, Japan, Bull. JSME, 25 (200), pp 277-283 (Feb 1982) 10 figs, 3 tables, 5 refs

Key Words: Shafts, Rotors, Critical speeds, Whirling, Viscous damping

Analytical results on the fundamental critical speed of a shaft in a viscous fluid are presented. When the fluid is set in motion by the shaft whirling, dynamic forces imposed on the fluid on the shaft are obtained by solving the two-dimensional Navier-Stokes equations under appropriate boundary conditions and on the assumption of small amplitude of the whirling motion. Added mass coefficients of the fluid and viscous damping coefficients are determined using these dynamic forces, and accordingly the equations of whirling motion of the shaft are derived. The critical speed of the shaft are found by solving these equations of whirl motion. In this analysis, configurations of the shaft are assumed to be a uniform elastic beam or a disk-attached elastic beam, whose both ends are simply supported by bearings. For the latter case, an experimental study was made in order to confirm the analytical results. From this study it was revealed that the critical speed decreases for large viscosity of the fluid, and when the fluid fills an annulus between the shaft and a cylinderical wall, the critical speed decreases for small annular gap width.

## 82-1343
## Impulse Response and Radiated Noise in an Air-Cooled Small Engine

N. Kojima, M. Murata, and M. Fukuda
Yamaguchi Univ., Tokiwadai, Ube., Japan, Bull. JSME, 25 (200), pp 234-240 (Feb 1982) 14 figs, 4 refs

Key Words: Frequency analysis, Engine noise, Engine vibration

A frequency analysis technique is proposed to identify various vibrations and noises induced by many impacts in a running engine. The frequency spectra of the vibration and noise which correspond to each impact in a particular time segment within one cycle are discussed by using this technique. This technique makes it possible to obtain accurate frequency characteristics of noise radiated in each time segment and the contribution ratio to the total engine noise, and to deduce the band frequency components of vibration and noise which are correlated to each impact produced in the engine structure. It is shown that the analysis technique proposed in this paper gives an effective means to clarify the mechanisms of the engine noise generation.

## 82-1344
## Subharmonic Flexural Oscillations in the Shaft Line of Large Turbosets

W. Kellenberger and R. Wohlrab

Brown Boveri Rev., 12 (68), pp 474-485 (Dec 1981) 11 figs, 10 refs

Key Words: Shafts, Flexural vibration, Subharmonic oscillations, Steam turbines

Smooth running of the revolving shaft line of a large steam turboset increases the reliability and availability of the plant to a decisive extent. There has recently been increased discussion on the possibility of subharmonic flexural oscillations and resonances in the shaft line. In the first part of this paper these nonlinear oscillations are treated using two theoretical models. Conditions necessary for their occurrence are a relatively large nonlinear restoring force of the shaft and low external damping. In the second part, the order of magnitude of the nonlinearity and damping is determined for actual shafts. A comparison between the two parts shows that no subharmonic flexural oscillations occur in steam turbosets under normal operation.

## 82-1345
## Modelling Low-cycle Torsional Fatigue Crack Growth under Variable Loadings

F.A. McClintock and R.O. Ritchie
Dept. of Mech. Engrg., Massachusetts Inst. of Tech., Cambridge, MA, "Mechanics of Fatigue" Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 1-9, 2 figs, 18 refs

Key Words: Shafts, Turbomachinery, Fatigue life, Crack propagation

To provide a basis for estimating the safe fatigue life in turbogenerator shafts subjected to the large transient oscillations of high speed reclosure, a model is developed for low cycle fatigue crack propagation in Mode III (anti-plane shear). Crack advance is considered to take place by a Mode II coalescence of cracks, initiated at inclusions ahead of the main crack front. This mechanism is consistent with the crack increment being about two orders of magnitude smaller than the crack tip displacement per reversal ($\Delta$CTD). For high torques, the concept of $\Delta$CTD is extended to strain intensity, $\Delta\Gamma \equiv \lim r\Delta\gamma$. If the damage is accumulated only near the crack, then the model gives a physical basis for the rainflow method of accumulating changes in strain intensity.

## 82-1346
## Computation of Natural Frequencies of Columns of Big Turbo-Generators (Berechnung der Eigenfrequenzen von Standern grosser Turbogeneratoren)

W.D. Kruger and W. Krause
VEB Bergmann-Borsig, Gorlitzer Maschinenbau, Maschinenbautechnik, 30 (12), pp 564-568 (1981) 12 figs, 2 tables, 13 refs
(In German)

Key Words: Generators, Turbogenerators, Columns, Natural frequencies

The reliable operation of big turbo-generators requires a knowledge and a forecast of the vibrational level of a generator column as exact as possible including the valuation of the influence of several structural elements on its dynamic behavior. An essentially extended model of computation of the generator column is represented and discussed in detail. The elaborated algorithm of solution for computation of natural frequencies of the model system is described. Numerical conversion and computation results are stated.

## 82-1347
## An Analysis of Unsteady Torque on a Two-Dimensional Radial Impeller

K. Imaichi, Y. Tsujimoto, and Y. Yoshida
ASME Paper No. 81-WA/FE-30

Key Words: Impellers, Transient excitation, Periodic excitation, Fluid-induced excitation

Unsteady flows around radial impellers are analyzed by the use of singularity methods. Unsteady torque is given for transient and/or sinusoidal flow rate and/or angular velocity fluctuation. It is shown that the unsteady torque can be divided into three components -- quasisteady, apparent mass and wake -- and the nature of each component is discussed.

## 82-1348
## Compressor Stability Analysis

S. Baghdadi and J.E. Lueke
Detroit Diesel Allison Div., General Motors Corp., Indianapolis, IN, ASME Paper No. 81-WA/FE-18

Key Words: Compressors, Dynamic stability

A dynamic compressor analysis applicable to axial flow compressors operating with a wide variety of inlet exhaust conditions (steady-state or dynamic, and with total pressure and/or total temperature inlet distortion patterns) has been developed as part of the Air Force/DDA Contract "Effects of Inlet Temperature Distortion on Gas Turbine Engine Stability." The analysis is described and analytical results are compared to data obtained during the test phase of the program.

**82-1349**

**Noise and Noise Abatement in Fans and Blowers -- a State of the Art Review**

W. Neise

Deutsche Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt e.V., Goettingen, West Germany, Rept. No. DFVLR-FB-80-16, 108 pp (1981)
PB82-129784

Key Words: Fans, Noise reduction

This report was prepared in order to describe the state of the art of the noise of industrial fans (ventilators). A review is given of the fan types commonly in use and their practical applications, of the mechanisms of the aerodynamic noise generation in fans, of theoretical and empirical prediction methods for fan noise, of acoustic similarity laws, and of noise reduction methods by means of the fan construction and fan operation. Measurement procedures are discussed with respect to the noise radiated from different parts of a fan. Considerations are made, for which classes of fan noise standards can be defined to characterize the noise emission of the various fan types; such noise standards are based on experimental data.

**82-1350**

**Transient Characteristics of a Centrifugal Pump During Starting Period**

H. Tsukamoto and H. Ohashi

Kyushu Inst. of Tech., Kitakyushu, Japan, ASME Paper No. 81-WA/FE-16

Key Words: Pumps, Centrifugal pumps, Transient response

A theoretical and experimental study has been made on the transient characteristics of a centrifugal pump during its rapid acceleration from standstill to final speed. Instantaneous rotational speed, flow-rate and total pressure rise are measured for various start-up schemes. Theoretical calculations for the prediction of transient characteristics are developed and compared with the corresponding experimental results.

## RECIPROCATING MACHINES

**82-1351**

**Advanced Superposition Methods for High Speed Turbopump Vibration Analysis**

C.E. Nielson and D. Campany

Rocketdyne Div., Rockwell International, Canoga Park, CA, Rept. No. NASA-CR-165379, RI/RD81-149, 96 pp (May 19, 1981)
N82-11465

Key Words: Turbomachinery, Pumps, Vibration analysis, Modal superposition method

The small, high pressure Mark 48 liquid hydrogen turbopump was analyzed and dynamically tested to determine the cause of high speed vibration at an operating speed of 92,400 rpm. This approaches the design point operating speed of 95,000 rpm. An advanced procedure for dynamics analysis was used in this investigation. The procedure involves developing accurate dynamic models of the rotor assembly and casing assembly by finite element analysis. The dynamically instrumented assemblies are independently rap tested to verify the analytical models. The verified models are then combined by modal superposition techniques to develop a completed turbopump model where dynamic characteristics are determined. The results of the dynamic testing and analysis obtained are presented and methods of moving the high speed vibration characteristics to speeds above the operating range are recommended. Recommendations for use of these advanced dynamic analysis procedures during initial design phases are given.

**32-1352**

**Spark Ignition Engine Model Building -- An Identification Approach to Throttle-Torque Response**

R.L. Morris, R.H. Borcherts, M.V. Warlick, and H.G. Hopkins

Engrg. and Res. Staff, Ford Motor Co., Dearborn, MI, Intl. J. Vehicle Des., 3 (1), pp 48-60 (Feb 1982)
4 figs, 2 tables, 15 refs

Key Words: Mathematical models, Parameter identification technique, Motor vehicle engines, Spark ignition engines

A rapidly obtained low-order sampled data description of the output response of driveshaft torque to throttle opening is described. Based upon a sampling interval of one engine revolution, the resulting fourth-order dynamic model is applicable over the range of 600-2000 rpm (vehicle speed 0-60 mph) for a 5.7 litre feedback carburetted engine and automatic transmission. Physical principles are used to obtain a block diagram of the system, and Landau's hyperstable identification algorithm is then used to determine the parameters of the model.

**82-1353**

**Characteristics of Fluidborne Noise Generated by Fluid Power Pumps (1st Report, Mechanism of**

**Generation of Pressure Pulsation in Axial Piston Pump)**

E. Kojima and H. Nagakura

Faculty of Engrg., Kanagawa Univ., 3-27-1, Rokkakubashi, Kanagawa-ku, Yokohama, Japan, Bull. JSME, 25 (199), pp 46-53 (Jan 1982) 11 figs, 3 tables, 9 refs

Key Words: Pumps, Noise generation, Fluid-induced excitation

Characteristics of fluidborne noise generated by an axial piston pump are presented. In this analysis a flow ripple due to compressibility of fluid is considered in addition to one due to pumping mechanism. The ripple due to compressibility is caused by an unsteady internal leakage which flows backward intermittently, at the neighborhood of bottom dead center, from the delivery chamber into the cylinder chamber. Since a steady and continuous leakage of piston pump is generally very little, only a capacitant type impedance due to compressibility of fluid in the delivery chamber is considered as pump source impedance. Experimental values of pressure ripple almost agree, up to about 10th harmonic, with calculated values based on foregoing mathematical models for flow ripple and source impedance. It is concluded that the flow ripple of piston pump is mostly due to fluid compressibility, and that the well-known effect of pumping mechanism on the flow ripple can almost be ignored in the case of a relatively high operating pressure.

## METAL WORKING AND FORMING

**82-1354**

**Design Analysis for the Control and Drive Retrofit of a Numerically Controlled Lathe**

S.L. Cotter

Los Alamos Scientific Lab., NM, Rept. No. CONF-800606-1, 10 pp (1980) (Pres. at Symposium on Incremental Motion Control Systems and Devices, Champaign, IL, June 2, 1980)
LA-UR-80-621

Key Words: Lathes, Parameter identification technique, Digital simulation

A system approach to the retrofit of a numerically controlled two-axis lathe was taken to identify component function and interrelation. The dynamic system of the motor and machine was modeled and parameter identification experiments were done. This model, in state equation form, was used with the parameters data as the basis of a digital simulation of the system. From this and further analysis of the control characteristics, recommendations for component selection were presented.

**82-1355**

**Calculation of Stability Behaviour of Machine Tools at Cutter Milling (Berechnung des Stabilitätsverhaltens von Werkzeugmaschinen beim Fräsen mit Messerkopfen)**

L. Rockhausen

Forschungszentrum des Werkzeugmaschinenbaues im VEB Werkzeugmaschinenkombinat, "Fritz Heckert," Karl-Marx-Stadt, Maschinenbautechnik, 31 (1), pp 21-23 (1982) 4 figs, 10 refs
(In German)

Key Words: Machine tools, Cutting, Dynamic stability

Self-excited oscillations at cutting machine tools often cause an inadequate rate of utilization of the installed power. The frame is copied by a beam model with six degrees of freedom per joint. For the cutting process a linear dependence of cutting force change upon chip thickness change is supposed owing to relative movement between tool and workpiece. The solution statement meeting the stability limit leads to a linear complex proper value problem of third class for a given frequence. The comparison shows a good correspondence between calculation and measurement.

**82-1356**

**Analysis of Vibratory Noise in the Sawing of Aluminum Extrusions**

K.T Yap

Ph.D. Thesis, Univ. of Wisconsin, Madison, WI, 257 pp (1981)
UM 8124640

Key Words: Noise generation, Cutting, Circular saws, Saws

High speed cutting of aluminum extrusions by circular saws generates sound pressure levels causing considerable concern relative to OSHA regulations. Aluminum sawing noise resulting from the saw blade and workpieces is categorized into two types: acceleration noise due to the mass-like vibration of the air near the blade tooth impact area and ringing noise resulting from workpiece and blade flexure at normal modes of vibration. A technique using laboratory impact tests provides a convenient evaluation of the relative contributions of these types of noise. It is shown that these tests reflect actual sawing conditions. Results presented demonstrate that reduction of acceleration noise can be reduced by surface damping, using constrained-layer damping concepts in clamping devices. Surface damping is also shown to decrease acceleration noise by increasing the mass effect of the vibrating workpiece.

**82-1357**
**On Optimum Hammers and Anvils**
R.B. Gupta
Dept. of Mech. Engrg., Univ. of Luleå, S-951 87 Luleå, Sweden, J. Sound Vib., 80 (2), pp 223-231 (Jan 22, 1982) 5 figs, 10 refs

Key Words: Hammers, Anvils, Maximax response, Impact response

Longitudinal elastic impact between a hammer and an anvil is studied with regard to maximizing the peak value of the impact force. For a given hammer an appropriately chosen elastic anvil can generate a maximax impact force which is greater than the corresponding value for a rigid anvil. The improvements can be up 50% for a class of hammer-anvil combinations. Such optimum combinations are determined for long, cylindrical hammers and finite conical anvils.

**82-1358**
**Vibration and Acoustic Data for a Punch Press**
L.L. Koss and J.A. Moffatt
Dept. of Mech. Engrg., Monash Univ., Clayton, Victoria 3168, Australia, J. Sound Vib., 80 (4), pp 543-554 (Feb 22, 1982) 4 figs, 4 tables, 14 refs

Key Words: Machinery noise, Presses, Vibration control, Mode shapes, Damping, Experimental test data

Mode shape, radiation ratio and damping data obtained from pure tone vibration shaker tests on a 170 kN mechanical C frame punch press are presented in this paper. The experimental results show the value of the radiation ratio to be very dependent upon the structure for frequencies below 1kHz. Above this frequency the assumption of unity for the radiation ratio can be made. Values of the damping ratio are of the order of 0·01 for the modes which have been defined; however, data from blanking operations show that this value can increase by a factor of two to three.

# STRUCTURAL SYSTEMS

## BRIDGES
(Also see Nos. 1407, 1495)

**82-1359**
**Investigation of the Vibrational Behaviour of a Cable-Stayed Bridge under Wind Loads**
J.W.G. van Nunen and A.J. Persoon
Natl. Aerospace Lab., Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands, Engrg. Struc., 4 (2), pp 99-105 (Apr 1982) 12 figs, 1 table, 4 refs

Key Words: Bridges, Cable-stayed bridges, Wind-induced excitation, Flutter, Vortex shedding

During the design stage of a new traffic bridge of the cable-stayed type an investigation has been carried out to determine the vibrational behavior of the structure under wind loads. On a two-dimensional model wind tunnel experiments were carried out to establish the flutter stability of the bridge and to determine resonance vibrations due to vortex shedding. During construction of the actual bridge, vibration measurements were performed and the wind-induced vibrational behavior of the structure was observed.

## BUILDINGS
(Also see No. 1495)

**82-1360**
**Model Noise Control Provisions for Building Codes and an Implementation Manual**
A.S. Harris, D.S. Keast, N.P. Miller, and T.J. Schultz Bolt, Beranek and Newman, Inc., Cambridge, MA, Rept. No. EPA-550/9-81-401, 105 pp (Aug 1981) PB82-134081

Key Words: Buildings, Noise control, Standards and codes

A model municipal noise control code for buildings has been developed. Also included is an implementation manual for this code. The provisions of the code were developed with three objectives in mind. First, they attempt to minimize the adverse health and welfare effects of intruding noise without requiring the construction of economically unreasonable buildings. Proposed standards for the outdoor reduction of noise levels are achievable with existing materials and construction techniques. Second, enforcement for the review of plans and for the acceptance of completed buildings are described. Third, this material should help jurisdictions develop a process of administration and enforcement that is compatible with existing building code procedures. The model provisions of the proposed building code contain performance standards. These standards are administered and enforced by review of plans and inspections during and after construction of buildings.

**82-1361**
**Review and Refinement of ATC 3-06 Tentative Seis-**

**mic Provisions. Report of Technical Committee 4: Concrete**

R.D. Marshall and K. Woodward

Natl. Bureau of Standards, Washington, DC, Rept. No. NBSIR-80-2111-4, 235 pp (Oct 1980)
PB82-130915

Key Words: Buildings, Seismic design, Standards and codes

This report is one of a series of reports that documents the deliberations of a group of professionals jointly selected by the Building Seismic Safety Council and the National Bureau of Standards and charged with reviewing the tentative provisions prior to the conduct of trial designs. The report contains the recommendations and records of the committee charged with review of the reinforced concrete design provisions. The committee made 19 recommendations for revisions to the tentative provisions. These recommendations were made to the parent group, the Joint Committee on Review and Refinement, and their action on these recommendations is documented in a companion report.

**82-1362**

**Response of Structures to Nonvertically Incident Seismic Waves**

J.E. Luco and H.L. Wong

Dept. of Appl. Mech. and Engrg. Sci., Univ. of California, San Diego, CA 92093, Bull. Seismol. Soc. Amer., 72 (1), pp 275-302 (Feb 1982) 17 figs, 2 tables, 24 refs

Key Words: Buildings, Reinforced concrete, Seismic response, Earthquake response, Containment structures, Nuclear power plants

A study of the earthquake response of symmetric elastic structures subjected to SH-wave excitation with different angles of incidence and to Rayleigh waves is presented. For SH-wave excitation, particular emphasis is given to the study of the possible reduction of the response due to filtering by the foundation and the torsional response. For Rayleigh wave excitation, the effects of the additional rocking associated with the vertical component of the excitation are investigated. The results obtained for models of a 10-story reinforced concrete building and the containment structure of a nuclear power plant reveal that the response for nonvertically incident waves is significantly different from that obtained on the basis of the usual assumption of vertically incident SH waves.

**82-1363**

**Probabilistic Evaluation of Safety of Buildings during Construction**

S. Karshenas

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 168 pp (1981)
UM 8127615

Key Words: Buildings, Wind-induced excitation

The safety of steel buildings constructed by the tier method is evaluated. Variations of reliability during construction for steel frames with rigid and flexible designs are examined. At each stage of construction, the potential modes of failure are identified and formulated for reliability analysis. The principal loading of concern is the maximum wind load over the critical stages of construction. Uncertainties associated with the properties of the structure at each stage of construction and the wind environment parameters are included in the formulation. The dynamic effect of wind on an incomplete frame is evaluated using elements of random vibration. In addition to the construction procedure and type of structural design, variations of reliability during construction due to changes in the planning and scheduling of the project are also examined. The reliability of a ten-story steel frame building, built by a common combination of crew and equipment, is examined in detail.

**82-1364**

**Variability of Tall Building Response to Earthquakes with Changing Epicentre Direction**

J.N. Yang, S. Sae-Ung, and Y.K. Lin

Dept. of Civil, Mech. and Environmental Engrg., The George Washington Univ., Washington, DC, Earthquake Engrg. Struc. Dyn., 10 (2), pp 211-223 (Mar-Apr 1982) 9 figs, 4 tables, 11 refs

Key Words: Buildings, Multistory buildings, Earthquake response, Seismic response

Using a 40-story building as an example, the structural response under the excitation of horizontal earthquake ground motion is shown to vary greatly with the direction from the building site to the epicentre. Two mathematical models are used to represent the ground motion: the stationary random process model and the evolutionary-type non-stationary random process model. The former model is suitable if the duration of the most intense portion of an earthquake is much longer than the fundamental natural period of the structure. The maximum standard deviations of selected structural response quantities are computed and plotted for all possible epicentre directions, and the information is believed to be useful for design purposes.

**82-1365**

**Horizontally Travelling Waves in a Group of Piles Taking Pile-Soil-Pile Interaction into Account**

J.P. Wolf and G.A. Von Arx
Electrowatt Engrg. Services Ltd., 8022 Zurich, Switzerland, Earthquake Engrg. Struc. Dyn., 10 (2), pp 225-237 (Mar-Apr 1982) 14 figs, 2 tables, 12 refs

Key Words: Pile structures, Interaction: soil-structure, Seismic response, Earthquake response, Buildings, Nuclear reactors

A reactor building founded on a large number of piles situated in a layered site is analyzed for an historic earthquake assumed to be propagating horizontally. Pile-soil-pile interaction is properly accounted for, incorporating the frequency-dependent stiffness and radiation damping. Compared to vertical incidence, the pile forces are increased and the piles close to the boundary are loaded more heavily than those in the center region of the basemat.

## TOWERS

### 82-1366
### Modern Developments in Wind Engineering: Part 3
E. Simiu
Ctr. for Bldg. Tech., Natl. Engrg. Lab., Natl. Bureau of Standards, Washington, DC 20234, Engrg. Struc., 4 (2), pp 66-74 (Apr 1982) 5 figs, 2 tables, 37 refs

Key Words: Towers, Chimneys, Wind-induced excitation

This is the third in a series of review papers devoted to the state-of-the-art in wind engineering. Previous papers were published in the October 1981 issue of Engineering Structures, pp 233-240 and 241-248.

## FOUNDATIONS
(Also see No. 1495)

### 82-1367
### Vibrational Characteristics of Soil Deposits with Variable Wave Velocity
G. Gazetas
Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY 12181, Intl. J. Numer. Methods Geomech., 6 (1), pp 1-20 (Jan-Mar 1982) 12 figs, 1 table, 27 refs

Key Words: Foundations, Soils, Vibration analysis, Machinery foundations

The paper studies certain dynamic characteristics of soil deposits with increasing wave velocities. Analytical solutions are presented for the fundamental periods, mode shapes and amplification functions due to vertically propagating shear waves and the effects of type (m) and rate ($\mu$) of heterogeneity are systematically investigated. Analytical-numerical techniques are used to study the attenuation with depth in a deposit of the vertical and horizontal displacements due to traveling of Rayleigh waves. Differences attributed to different heterogeneities are discussed in connection with the machine isolation problem and the steady-state vibration technique for soil exploration. The dependence on soil heterogeneity of the time-distance response curves, obtained during seismic refraction surveys, is graphically illustrated.

### 82-1368
### Dynamic Response of an Embedded Rectangular Foundation to Antiplane Shear Waves
K.P. Meade and L.M. Keer
Northwestern Univ., Evanston, IL 60201, Intl. J. Solids Struc., 18 (3), pp 249-261 (1982) 10 figs, 20 refs

Key Words: Foundations, Shear waves, Periodic response

The steady state response of a deep, narrow, rectangular foundation to antiplane shear waves is studied. Consideration is given first to the dynamic response of a single rigid line inclusion. This result is used to model a rectangular foundation in a manner similar to Haritos and Keer who studied the problem of a rigid block partially embedded in an elastic half-space. Because the problem is antiplane, the results arrived at for the deep, narrow, rectangular foundation also apply to a shallow, wide, rectangular foundation.

### 82-1369
### Seismic Safety Analysis of Slopes
C.-J. Chang
Ph.D. Thesis, Purdue Univ., 137 pp (1981)
UM 8200651

Key Words: Soils, Seismic response, Computer programs

To obviate the complicated calculation of progressive failure to stress-strain approach and the inaccuracy of traditional pseudo static analysis in seismic slope stability analysis, it requires an effective method which can directly determine critical state of the slope and explicitly account for the effects of earthquake on the slope stability. The present

research effort is an attempt to develop a model to evaluate the critical state and subsequently the necessary calculation of effects of earthquake in slopes based on the framework of conventional pseudo-static analysis. A computer program is developed for the analysis of seismic slope stability.

## HARBORS AND DAMS

(Also see No. 1567)

**82-1370**

### Two-Dimensional Dynamic Analysis of Concrete Gravity and Embankment Dams Including Hydrodynamic Effects

J.F. Hall and A.K. Chopra
Dept. of Civil Engrg., Univ. of California, Berkeley, CA, Earthquake Engrg. Struc. Dyn., 10 (2), pp 305-332 (Mar-Apr 1982) 20 figs, 12 refs

Key Words: Dams, Earthquake response, Interaction: structure-fluid, Hydrodynamic excitation, Frequency domain, Finite element technique

An analysis procedure in the frequency domain is developed for determining the earthquake response of two-dimensional concrete gravity and embankment dams including hydrodynamic effects; responses of the elastic dams and compressible water are assumed linear. The dam and fluid domain are treated as substructures and modeled with finite elements. The only geometric restriction is that an infinite fluid domain must maintain a constant depth beyond some point in the upstream direction. For such an infinite uniform region, a finite element discretization over the depth is combined with a continuum representation in the upstream direction. The fluid domain model approximately accounts for interaction between the fluid and underlying foundation medium through a damping boundary condition applied along the reservoir bottom, while the dam foundation is assumed rigid. Several examples are presented to demonstrate the accuracy of the fluid domain model and to illustrate dam responses obtained from the analysis procedure.

**82-1371**

### Hydrodynamic Effects in the Dynamic Response of Concrete Gravity Dams

J.F Hall and A.K. Chopra
Dept. of Civil Engrg., Univ. of California, Berkeley, CA, Earthquake Engrg. Struc. Dyn., 10 (2), pp 333-345 (Mar-Apr 1982) 9 figs, 3 refs

Key Words: Dams, Earthquake response, Interaction: structure-fluid, Hydrodynamic excitation, Frequency domain

Hydrodynamic effects in the acceleration response of concrete gravity dams to harmonic ground motion are investigated. The effects include the presence of water, compressibility of water, interaction between the fluid and underlying foundation medium, shape of the fluid domain, and the extent of excitation applied to an infinite fluid domain under vertical ground motion.

**82-1372**

### Non-Linear Seismic Response of Arch Dams

A. Niwa and R.W. Clough
Earthquake Engrg. Res. Ctr., Univ. of California, Berkeley, CA, Earthquake Engrg. Struc. Dyn., 10 (2), pp 267-281 (Mar-Apr 1982) 16 figs, 12 refs

Key Words: Dams, Earthquake damage, Experimental test data

An experimental study of nonlinear mechanisms that may occur during intense seismic response of arch dams is described in this paper. The presentation deals with three types of nonlinearity that were observed during shaking table model studies: monolith joint opening, cantilever cracking, and reservoir cavitation at the dam face. The monolith joint opening phenomenon was represented by a segmental arch ring model that simulated a horizontal slice of a prototype dam. The cantilever cracking and reservoir cavitation mechanisms were studied using a model gravity dam section. The principal conclusion of the investigation was that shaking table experiments provide a practical means of studying the nonlinear earthquake response of concrete arch dams, including their actual failure mechanisms.

## POWER PLANTS

(Also see Nos. 1362, 1421, 1460, 1464, 1466, 1469, 1470, 1471, 1472, 1536, 1570)

**82-1373**

### Variability in Dynamic Characteristics and Seismic Response Due to the Mathematical Modeling of Nuclear Power Plant Structures

B.J. Benda, J.J. Johnson, and P.D. Smith
Struc. Mechanics Assoc., Inc., San Ramon, CA 94583, Nucl. Engrg. Des., 67 (1), pp 109-123 (Oct 1981) 17 figs, 2 tables, 9 refs

Key Words: Nuclear power plants, Power plants (facilities), Seismic response

Calculated variations in dynamic characteristics and seismic response of nuclear power plant structures caused by different modeling assumptions are quantified. Four different mathematical models were created to describe the same structure, the Zion nuclear power station auxiliary/fuel-handling/diesel-generator complex. The modeling idealizations are a detailed finite element model, a detailed finite element model with masses lumped at selected nodes, a detailed finite element model with the constraint of rigid floors, and an equivalent beam model. Dynamic characteristics and response quantities are determined for the models and compared. Results indicate that large variations in dynamic characteristics and response can be introduced by modeling assumptions when a need exists to reduce the number of dynamic degrees of freedom.

**82-1374**

**Response of Base-Isolated Nuclear Structures to Earthquakes**

A. Kamel

Ph.D. Thesis, Purdue Univ., 161 pp (1981)

UM 8200687

Key Words: Nuclear power plants, Isolation, Base excitation, Base isolation, Elastomeric bearings

A method for evaluation of the dynamic response of base-isolated nuclear power plants and the performance of aseismic rubber bearings in the vertical direction is presented in this dissertation. The method is based on the Finite Element analysis technique in which the structure is subjected to the ground motion filtered through the base isolation system. The isolation system consists of two concrete rafts separated by concrete pedestals and aseismic rubber bearings. The concrete pedestals are positioned on the lower raft, which rests on the ground, and are located on top of the concrete pedestals and are modeled by viscoelastic elements. The vertical ground motions of four major earthquakes are used as input excitations in this study. It is assumed that the motion of the lower raft is represented by the ground motion during an earthquake, and there is no interaction between the soil and the lower raft. Equations of motion for the modeled structure are derived in matrix form and a step by step numerical integration scheme is used to solve these equations. It is found that a well designed isolation system with adequate damping has a good performance, and can be used for isolation purposes against earthquakes satisfactorily.

**82-1375**

**Dynamic Structural Design Procedures Including Fluid Structure Interaction**

R.J. Scavuzzo

Dept. of Mech. Engrg., The Univ. of Akron, Akron, OH, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engineering, Solar Energy Divisions, Denver, CO, June 21-25, 1981. ASME PVP-52, P.Y. Chen, ed., pp 135-143, 4 figs, 1 table, 19 refs

Key Words: Interaction: structure-fluid, Submerged structures, Nuclear reactor components, Seismic response, Fluid-induced excitation, Design techniques

Design procedures for the calculation of the dynamic response of submerged structures are outlined and the literature discussing various approaches is reviewed. For low frequency vibratory excitation, fluid inertia effects often dominate the dynamic response of submerged structures. Virtual mass methods, often employed to analyze this class of problems, are outlined. Fluid compressibility governs the dynamic response of structures subjected to wave impact. Procedures used to analyze this class of problem are also described and referenced.

**82-1376**

**Flow-Induced Vibration Testing Scale Modeling Relations**

T.M. Mulcahy

Components Tech. Div., Argonne Natl. Lab., Argonne, IL, "Flow-Induced Vibration Design Guidelines," Joint Conf. of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 111-125, 1 fig, 1 table, 47 refs

Key Words: Nuclear reactor components, Vibration tests, Scaling, Fluid-induced excitation, Design techniques

Similitude relationships currently employed in the design of flow induced scale model tests of nuclear reactor components are reviewed. Emphasis is given to understanding the origins of the similitude parameters as a basis for discussion of the inevitable distortions which occur in design verification testing of entire reactor systems and in feature testing of individual components made during the design process to determine whether features of the component design will create detrimental flow-induced vibration mechanisms. Distortions of similitude parameters made in current test practice are enumerated, and limitations in the use of specific distortions in model designs are evaluated based on the current understanding of flow-induced vibration mechanisms and structural response.

**82-1377**

**Flow Induced Vibration in the Design of Nuclear Components**

G.J. Bohm and S.W. Tagart
Westinghouse Electric Corp., Pittsburgh, PA, "Flow-Induced Vibration Design Guidelines," Joint Conf. of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 1-10, 1 table, 25 refs

Key Words: Nuclear reactor components, Fluid-induced excitation, Design techniques

This introductory paper to the monograph series on flow-induced vibration briefly discusses the basic phenomena observed in LWR systems, the history of the problems and gives background information on how the monograph series is related to the ASME Section III Code. Flow-induced vibration is at a state-of-art where detailed design procedures cannot be finalized in a standard code form for all types of components and flow conditions of interest. What has been done is to identify flow vibration mechanisms, quantitatively describe their effects on components and provide guidance to the designers. Present technology is based on information obtained on tests combined with analytical methods developed for a better understanding of the phenomena.

### 82-1378
### Flow-Induced Vibration Testing of BWR Feedwater Spargers

M.R. Torres
General Electric Co., San Jose, CA, "Flow-Induced Vibration of Power Plant Components," Pressure Vessels and Piping Conf. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 159-176, 19 figs, 4 tables

Key Words: Nuclear power plants, Fluid-induced excitation, Vibration tests

Feedwater spargers are used in boilers to inject and evenly distribute cold feedwater which replaces the steam removed for power generation. Typically in the power industry, it is standard practice to minimize thermal cycling of the vessel nozzle of a boiler or steam generator by use of a thermal sleeve. The thermal sleeve is usually attached to the sparger and slip-fit into the nozzle. Certain configurations and operational conditions of these designs incur excessive narrow band limit cycle vibrations. To understand the cause of vibration and properly verify improved designs, cold flow tests were performed in a full-scale mockup test facility. Flow-induced vibrations similar to those measured and observed in actual plant operation were reproduced at the test facility. It was determined experimentally that leakage flow between the vessel nozzle and thermal sleeve was the most important parameter causing this vibration. Several feedwater sparger designs were investigated for susceptibility to this type of vibration phenomenon.

## OFF-SHORE STRUCTURES
(Also see No. 1429)

### 82-1379
### OTEC Cold Water Pipe Design for Problems Caused by Vortex-Excited Oscillations

O.M. Griffin
Marine Technology Div., Naval Res. Lab., Washington, DC, Ocean Engrg., 8 (2), pp 129-209 (1981)

Key Words: Off-shore structures, Power plants (facilities), Pipelines, Vortex-induced vibration, Fatigue life

Vortex-excited oscillations of marine structures result in reduced fatigue life, large hydrodynamic forces and induced stresses, and sometimes lead to structural damage and to destructive failures. The cold water pipe of an Ocean Thermal Energy Conversion (OTEC) plant is nominally a bluff, flexible cylinder with a large aspect ratio (L/D = length/diameter), and is likely to be susceptible to resonant vortex-excited oscillations. The objective of this paper is to survey recent results pertaining to the vortex-excited oscillations of structures in general and to consider the application of these findings to the design of the OTEC cold water pipe. Practical design calculations are given as examples throughout the various sections of the report.

### 82-1380
### Hydrodynamic Loads on Flexible Marine Structures Due to Vortex Shedding

M.J. Every, R. King, and O.M. Griffin
Cranfield, Bedford, UK, ASME Paper No. 81-WA/FE-24

Key Words: Off-shore structures, Drilling platform, Vortex-induced vibration, Fluid-induced excitation

This paper makes a comparison of experimental measurements and a recently developed methodology for the prediction of the increase in the steady drag of a cylinder undergoing vortex induced vibrations. The experimental results were obtained during the development of a means to reduce the flow-induced vibration of a cable-suspended pile for the COGNAC platform installation and agree well with the pre-

dictions made in this paper. A brief consideration is made of some of the authors' experience of methods used to reduce vortex induced vibrations, and hence stress levels.

# VEHICLE SYSTEMS

## GROUND VEHICLES

(Also see Nos. 1493, 1561)

### 82-1381

**Airbag and Belt Pretensioner Provide Increased Safety for Driver and Front Passenger (Erhöhung der Insassensicherheit durch Airbag und Gurtstrammer)**

L. Brambilla

Automobiltech. Z., 84 (2), pp 77-80, 83 (1982) 17 figs, 3 refs

(In German)

Key Words: Safety restraint systems, Seat belts, Air bags (safety restraint systems)

A safety restriant system comprising an airbag in the steering wheel in addition to the three-point safety belt and the belt pretensioner on the front passenger side, which will be available on all Mercedes passenger-car models in 1982, is described. The author also discusses the individual components and functions of the system such as a gas generator, air bags, belt pretensioners, electronic release mechanism, release function, storage function, risk injury, and test results.

### 82-1382

**Simulation of Vehicle Collisions Using Scale Models -- Analysis of Frontal and Side Impacts**

H. Ohmae, K. Kurihara, Y. Okami, M. Morisawa, and T.B. Sato

Japan Automobile Res. Inst., Inc., Tsukuba, Ibaraki-ken, Japan, Intl. J. Vehicle Des., 3 (1), pp 61-76 (Feb 1982) 12 figs, 1 table, 11 refs

Key Words: Collision research (automotive), Crashworthiness, Scaling, Model testing

Collision experiments using model vehicles were considered to simplify the processes and to minimize costs of experiments using full-scale vehicles. Model vehicles were fabricated and impact experiments were performed and compared for crashworthiness with that of full-scale vehicles. The crashworthiness of model vehicles corresponds well to that of full-scale vehicles and the impacts of model vehicles can simulate those of full-scale vehicles. These results indicate that experiments using model vehicles are a very effective means of estimating the vehicle crashworthiness at impact.

### 82-1383

**Non-Contacting Suspension and Propulsion Systems for Transportation Applications**

R. Katz, C. Swanson, and L. del Cid

METRIK Div., MITRE Corp., McLean, VA, Rept. No. MTR-80W376, DOT/RSPA/DPB/25-81/16, 197 pp (May 1981)

PB82-135591

Key Words: Ground effect machines, Transportation vehicles, Urban transportation

This report documents world-wide research and development in non-contacting propulsion and/or suspension for urban and intercity ground transportation. The final section deals with recent research programs in non-contacting propulsion and suspension technology.

### 82-1384

**Structural-Acoustic Finite Element Analysis of the Automobile Passenger Compartment: A Review of Current Practice**

D.J. Nefske, J.A. Wolf, Jr., and L.J. Howell

Engrg. Mechanics Dept., General Motors Res. Labs., Warren, MI 48090, J. Sound Vib., 80 (2), pp 247-266 (Jan 22, 1982) 17 figs, 1 table, 34 refs

Key Words: Automobiles, Interior noise, Cavities, Finite element technique

This paper contains a brief review of the formulation of the finite element method for structural-acoustic analysis of an emclosed cavity, and illustrations are given of the application of this analytical method at General Motors Corporation to investigate the acoustics of the automobile passenger compartment. Low frequency noise in the passenger compartment (in approximately the 20-200 Hz frequency range) is of primary interest, and particularly that noise which is generated by the structural vibration of the wall panels of the compartment. The topics which are covered in the paper

include the computation of acoustic modes and resonant frequencies of the passenger compartment, the effect of flexible wall panels on the cavity acoustics, the methods of direct and modal coupling of the structural and acoustic vehicle systems, and forced vibration analysis illustrating the techniques for computing panel-excited noise and for identifying critical panels around the passenger compartment. The capabilities of the finite element method are illustrated by applications to the production automobile, and experimental verifications of the various techniques are presented to illustrate the accuracy of the method.

**82-1385**

**Fatigue Analysis of Railway Freight Car Wheels under Thermal Loading Conditions**

T.J. Thomas, V.K. Garg, and S. Nair

Illinois Inst. of Tech., Chicago, IL, Intl. J. Vehicle Des., 3 (1), pp 90-102 (Feb 1982) 19 refs, 4 tables, 18 refs

Key Words: Railroad trains, Freight cars, Wheels, Vehicle wheels, Fatigue life, Thermal effects

When a wheel is subjected to repeated thermal loading due to drag braking, cracks can develop and propagate due to fatigue. Wheels of 36, 33, and 28 inch diameter were studied using the finite-element method. The wheels were subjected to drag braking of 30, 40, and 50 hp, each applied for 30 minutes. The fatigue life was computed for an assumed load history using the Miner's linear cumulative damage rule. The temperature distribution in the wheel was obtained by means of the DOT program. The CREEP-PLAST program was used to compute the stress and strain distributions. The stress and strain values increase as the braking horsepower is increased. For the same loading the fatigue life is lower for the smaller wheels as compared to the fatigue life of the larger wheels.

**82-1386**

**Properties of Antilock Systems: Descriptive Parameters Used in Analyzing the Braking and Handling of Heavy Trucks. Volume 5**

C.C. MacAdam and P.S. Fancher

Highway Safety Res. Inst., Univ. of Michigan, Ann Arbor, MI, Rept. No. UM-HSRI-81-19-5, 95 pp (May 1981)

PB82-133273

Key Words: Trucks, Braking effects, Suspension systems (vehicles), Steering effects, Experimental test data, Computer-aided techniques

In this volume, results of laboratory tests performed on five commercial air brake antilock systems are discussed. A hybrid computer has been used to simulate wheel dynamics and to control test sequencing. Test results for each system under a variety of simulated test conditions have been digitized and stored on magnetic tape.

## SHIPS

(See Nos. 1426, 1540, 1566)

## AIRCRAFT

(Also see Nos. 1454, 1574, 1575, 1576)

**82-1387**

**Helicopter Rotor Trailing Edge Noise**

R.H. Schlinker and R.K. Amier

United Technologies Res. Ctr., Hartford, CT, Rept. No. NASA-CR-3470, 150 pp (Nov 1981)

N82-11859

Key Words: Helicopters, Rotors, Blades, Noise generation, Wind tunnel testing

A two dimensional section of a helicopter main rotor blade was tested in an acoustic wind tunnel at close to full-scale Reynolds numbers to obtain boundary layer data and acoustic data for use in developing an acoustic scaling law and testing a first principles trailing edge noise theory. Results were extended to the rotating frame coordinate system to develop a helicopter rotor trailing edge noise prediction. Comparisons of the calculated noise levels with helicopter flyover spectra demonstrate that trailing edge noise contributes significantly to the total helicopter noise spectrum at high frequencies. This noise mechanism is expected to control the minimum rotor noise.

**82-1388**

**Response Characteristics of a Linear Rotorcraft Vibration Model**

D.L. Kunz

U.S. Army Res. and Tech. Labs. (AVRADCOM), Ames Res. Ctr., Moffett Field, CA, J. Aircraft, 19 (4), pp 297-303 (Apr 1982) 13 figs, 1 table, 7 refs

Key Words: Helicopters, Vibration control, Parametric response, Harmonic balance method

A fully coupled vibration model, consisting of a rotor with only flapping degrees of freedom plus pylon and fuselage pitching motion, was used in a parametric study undertaken to investigate the response characteristics of a simplified helicopter. Among the parameters studied were uncoupled body frequency, blade stiffness, hinge offset, advance ratio, and mast height. Results from the harmonic balance solution of the equations of motion show how each of these quantities affects the response of the model. The results also indicate that there is a potential for reducing vibration response through the judicious definition of the design parameters.

**82-1389**

**Aircraft Lateral Parameter Estimation from Flight Data with Unsteady Aerodynamic Modeling**

W.R. Wells, S.S. Banda, and D.L. Quam

Wright State Univ., Dayton, OH, J. Aircraft, 19 (3), pp 206-210 (Mar 1982) 3 figs, 8 tables, 7 refs

Key Words: Aircraft, Parameter identification technique, Frequency domain method, Fast Fourier transform

An unsteady aerodynamic model for aircraft lateral motion was considered in the development of a parameter extraction algorithm in the frequency domain. This algorithm was applied to flight test data. The data were transformed into the frequency domain by the use of fast Fourier transform algorithms. Also investigated was the sensitivity of the extracted parameters to the control input with the inclusion of unsteady aerodynamic modeling.

**82-1390**

**Aircraft Parameter Identification in the Presence of Atmospheric Turbulence**

H. Okubo, T. Kanou, and M. Kobayakawa

Dept. of Aeronautical Engrg., Univ. of Osaka Prefecture, Mem. Fac. Engrg., Kyoto Univ., 43 (3), pp 364-375 (July 1981) 5 figs, 3 tables, 7 refs

Key Words: Aircraft, Parameter identification technique, Wind-induced excitation

The method for identifying the unknown parameters in the dynamics of an aircraft from flight data affected by random disturbances due to wind gusts is investigated. Two general algorithms suitable for applying to such stochastic environments – the method of maximum likelihood estimation and the extended Kalman filter technique -- are examined for capability by numerical simulations. The advantages and shortcomings of each algorithm are discussed in detail, which leads to the conclusion that the combined use of the two algorithms provides a powerful on-line technique, insensitive to initial parameter estimates.

**82-1391**

**Minimum Mass Sizing of a Large Low-Aspect Ratio Airframe for Flutter-Free Performance**

W.H. Greene and J. Sobieszczanski-Sobieski

NASA Langley Res. Ctr., Hampton, VA, J. Aircraft, 19 (3), pp 228-234 (Mar 1982) 8 figs, 1 table, 12 refs

Key Words: Aircraft, Flutter

A procedure for sizing an airframe for flutter-free performance is demonstrated on a large, flexible supersonic transport aircraft. The procedure is based on using a two-level reduced basis or modal technique for reducing the computational cost of performing the repetitive flutter analyses. The supersonic transport aircraft exhibits complex dynamic behavior, has a well-known flutter problem and requires a large finite-element model to predict the vibratory and flutter response. Flutter-free designs are produced with small mass increases relative to the wing structural weight and aircraft payload. In view of the ability of the resizing procedure to handle this supersonic transport configuration, it seems likely that the method could be used for many other aircraft.

**82-1392**

**An Influence Coefficient Method for the Application of the Modal Technique to Wing Flutter Suppression of the DAST ARW-1 Wing**

S. Pines

Analytical Mechanics Associates, Inc., Hampton, VA, Rept. No. NASA-CR-165772, AMA-81-25, 49 pp (Nov 1981)

N82-11070

Key Words: Aircraft wings, Flutter, Vibration control, Influence coefficient method

The methods used to compute the mass, structural stiffness, and aerodynamic forces in the form of influence coefficient matrices as applied to a flutter analysis of the Drones for Aerodynamic and Structural Testing (DAST) Aeroelastic Research Wing are given. The DAST wing was chosen because wind tunnel flutter test data and zero speed vibration data of the modes and frequencies exist and are available for comparison. A derivation of the equations of motion that

can be used to apply the modal method for flutter suppression is included. A comparison of the open loop flutter predictions with both wind tunnel data and other analytical methods is presented.

**82-1393**

**Unsteady Response of Rectangular Wings in Spanwise Uniform Shear Flow**

M. Kobayakawa

Kyoto Univ., Kyoto, Japan, AIAA J., 20 (4), pp 471-476 (Apr 1982) 11 figs, 8 refs

Key Words: Aircraft wings, Fluid-induced excitation, Aerodynamic loads

In engineering applications it is important to estimate aerodynamic forces on wings in nonuniform flow. Wakes produced by objects ahead of wings frequently affect the performance of airplanes, turbomachines, etc. In this paper, a theory of wings oscillating in shear flow is presented. The whole flowfield is assumed to be inviscid and incompressible, and the shear flow velocity is assumed to vary linearly along the wing span. For this problem, lifting surface theory is applied. An integral equation, which is similar to that for potential flow, is derived under the assumption of small perturbations, and then solved numerically by the mode function method. Results are compared for several frequencies and show that the effect of shear is not large except in the limiting case. However, the generalized forces and gust response functions are affected by the shear to some extent, even when the degree of shear is moderate. The effect increases as the frequency becomes larger.

**82-1394**

**Dynamic Analysis of the Flat Spin Mode of a General Aviation Aircraft**

M.B. Tischler and J.B. Barlow

Systems Technology, Inc., Hawthorne, CA, J. Aircraft, 19 (3), pp 198-205 (Mar 1982) 4 figs, 4 tables, 27 refs

Key Words: Aircraft, Dynamic analysis

The properties of the flat spin mode of a general aviation configuration have been studied through analysis of rotary balance data. The equilibrium state is predicted well from rotary balance data. Linearized analyses about the flat spin attitude show the existence of two coupled pitch-roll modes and a decoupled yaw mode. The stability of the flat spin mode has been examined extensively using numerical linearization, classical perturbation methods, and reduced order models. The stability exhibited by the time histories and the eigenvalue analyses is shown to be strongly dependent on the oscillatory aerodynamic derivatives. Explicit stability criteria are obtained from the reduced order models.

**82-1395**

**Oscillating Supersonic/Hypersonic Wings at High Incidence**

W.H. Hui, M.F. Platzer, and E. Youroukos

Naval Postgraduate School, Monterey, CA, AIAA J., 20 (3), pp 299-304 (Mar 1982) 8 figs, 11 refs

Key Words: Aircraft wings, Stability, Aerodynamic loads

An approximate analytic method is developed for predicting the aerodynamic stability of oscillating supersonic/hypersonic flat wings at a mean angle of attack. It uses the known exact unsteady unified supersonic/hypersonic flow solution for a two-dimensional flat plate plus the strip theory approximation to obtain the formulas for the stability derivatives. They are applicable for wings of arbitrary planform shape at arbitrary angles of attack provided the shock wave is attached to the leading edge of the wing. Good agreement is obtained with existing theories in various special cases. The formulas for stability derivatives given here become exact in the Newtonian limit.

**82-1396**

**Ground Reflection Interference in Aircraft Noise Measurements (Bodenreflexionseffekte bei Fluglärmmessungen)**

W.M. Dobrzynski

Abteilung Technische Akustik der Deutschen Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt (DFVLR), Postfach 3267, D-3300 Braunschweig, Z. Flugwiss., 5 (6), pp 367-374 (1981) 11 figs, 6 refs

(In German)

Key Words: Aircraft noise, Noise measurement

For the purposes of noise certification for propeller-driven aircraft (not exceeding 5.7t) microphones are positioned 1.2 m above the ground and the maximum A-weighted flyover noise level is determined for certifying the aircraft. Since an effect of ground reflection interferences on the flyover noise signature must be expected in this case an analytical/experimental study was initiated to determine the influ-

ence of ground reflections on the maximum A-weighted aircraft noise level. Flyover noise measurements were conducted with various propeller aircraft employing both microphones 1.2 m above ground and directly on the ground, the latter serving as a reference. The results of that study show conclusively that, depending on the respective propeller rotational speed and number of blades, level differences of up to 3 dB(A) can be obtained due to ground reflection interferences, compared to the unaffected signal level.

### 82-1397

### On the Sonic Fatigue Life Estimation of Skin Structures at Room and Elevated Temperatures

S. Maekawa
Kawasaki Heavy Industries Ltd., Gifu, Japan, J. Sound Vib., 80 (1), pp 41-59 (Jan 8, 1982) 13 figs, 15 refs

Key Words: Aircraft, Fatigue life

Fighter/trainer empennages and STOL (short take-off and landing) aircraft flap systems are subjected to severe acoustic pressure levels as high as 150-170 dB. As a result, acoustic fatigue has become one of the major factors in design. Empennages and flap systems are also subject to high temperatures and thus the influence of thermal buckling on fatigue life must be taken into consideration. To estimate the sonic fatigue life of skin structures, combined use is made of the Monte Carlo method of nonlinear panel response analysis and local stress-strain simulations with theological models. Calculations were conducted and comparison of the results with experimental data shows that the method estimates the sonic fatigue life accurately when adequate values of fatigue notch factors are chosen. Example calculations with thermal as well as static pressure effects were also carried out and the effect of thermal buckling on sonic fatigue life is clarified.

### 82-1398

### Sonic Fatigue Testing of an Advanced Composite Aileron

J. Soovere
Lockheed-California Co., Burbank, CA, J. Aircraft, 19 (4), pp 304-310 (Apr 1982) 20 figs, 2 tables, 4 refs

Key Words: Aircraft wings, Composite materials, Acoustic fatigue, Fatigue tests

The sonic fatigue test program to verify the design of the composite inboard aileron for the L-1011 airplane is described. The composite aileron is fabricated from graphite/epoxy minisandwich covers which are attached to graphite/epoxy front spar and ribs, and to an aluminum rear spar with fasteners. The program covers the development of random fatigue data by means of coupon testing and modal studies on a representative section of the composite aileron, culminating in the accelerated sonic fatigue proof test. The composite aileron sustained nonlinear panel vibration during the proof test without failure. Viscous damping coefficients as low as 0.4% were measured on the panels. The effects of moisture conditioning and elevated temperature on the random fatigue life of both undamaged and impact damaged coupons were investigated. The combination of impact damage, moisture, and a 180° F temperature could reduce the random fatigue life by 50%.

### 82-1399

### The Accuracy of Source Distributions Measured by Using Polar Correlation

S.A.L. Glegg
Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 80 (1), pp 31-40 (Jan 8, 1982) 2 figs, 1 table, 4 refs

Key Words: Jet engines, Jet noise, Noise source identification

The evaluation of jet noise source distributions as obtained by using the polar correlation technique is discussed. The accuracy with which this, or any other, technique can measure a jet noise source distribution is limited by the analytical model used to describe the source distribution and the statistical estimate which can be made of the randomly fluctuating source strengths. Both these problems are considered and criteria are developed for the accuracy of source location data in terms of the measurement parameters.

### 82-1400

### A Monitoring System for Aircraft Noise Measurements

V. Mestre and F. Greve
Vincent Mestre Associates, Newport Beach, CA, S/V Sound Vib., 16 (2), pp 13-16 (Feb 1982)

Key Words: Aircraft noise, Noise measurement

An unattended aircraft area noise monitoring system which was in operation for three years is described. This area monitor was installed to determine the location of the 65 CNEL contour under the approach path to Marine Corps Air Station El Toro located south of Santa Ana, CA. Accord-

ing to local land use planning guidelines, no residential land uses are permitted in areas with noise exposures greater than 65 CNEL. Spot measurements indicated great statistical variation in noise levels caused by military aircraft. Therefore, continuous monitoring at several locations was initiated. The resulting data were processed by a disc-based minicomputer system for further statistical treatment to accurately determine the CNEL.

**82-1401**
**On the Generation of Side-Edge Flap Noise**
M.S. Howe
Bolt, Beranek and Newman, Inc., 50 Moulton St., Cambridge, MA 02138, J. Sound Vib., 80 (4), pp 555-573 (Feb 22, 1982) 4 figs, 2 tables, 21 refs

Key Wods: Aircraft noise, Noise generation

A theory is proposed for estimating the noise generated at the side edges of part span trailing edge flaps in terms of pressure fluctuations measured just in-board of the side edge on the upper surface of the flap. Asymptotic formulae are developed in the opposite extremes of Lorentz contracted acoustic wavelength large/small compared with the chord of the flap. Interpolation between these limiting results enables the field shape and its dependence on subsonic forward flight speed to be predicted over the whole frequency range. It is shown that the mean width of the side edge gap between the flap and the undeflected portion of the airfoil has a significant influence on the intensity of the radiated sound. The results indicate that the noise generated at a single side edge of a full scale part span flap can exceed that produced along the whole of the trailing edge of the flap by 3 dB or more.

## MISSILES AND SPACECRAFT
(Also see Nos. 1548, 1563, 1564)

**82-1402**
**MHD Measurement of Acoustic Velocities in Rocket Motor Chambers**
M.M. Micci and L.H. Caveny
Princeton Univ., Princeton, NJ, AIAA J., 20 (4), pp 516-521 (Apr 1982) 7 figs, 2 tables, 19 refs

Key Words: Solid rocket propellants, Acoustic waves, Magnetohydrodynamics

A linear analysis of longitudinal acoustic waves (either forced or self-induced) at or near the fundamental frequency in solid rocket chambers revealed that the acoustic velocity phase angle relative to the head-end pressure at the chamber midpoint is strongly dependent on the real part of the overall pressure-coupled response function and the imaginary part of the overall velocity-coupled response function. A flowmeter based on Faraday's Law was devised to demonstrate the feasibility of such velocity measurements under rocket motor conditions. The interaction of an externally-excited magnetic field with the unsteady velocity of high-temperature combustion gases results in a corresponding unsteady electrical potential whose magnitude is proportional to the flow velocity.

# BIOLOGICAL SYSTEMS

## HUMAN

**82-1403**
**Impulse Noise-Induced Hearing Loss in Drop Forge Operators and the Energy Concept**
W.J. Sulkowski and A. Lipowczan
Inst. of Occupational Medicine, Teresy 8, 90-950 Lodz, Poland, Noise Control Engrg., 18 (1), pp 24-29 (Jan-Feb 1982) 8 figs, 3 tables, 14 refs

Key Words: Industrial facilities, Noise generation, Human response

Detailed noise measurement and audiometric testing were carried out in a large drop-forge factory. A computerized system of data processing was employed for the evaluation of impulse noise. The audiometric results of 424 drop-forge workers (after excluding those with ear pathology and previous noise exposure) were analyzed according to age, years of exposure, and in terms of percent of hearing loss, calculated according to the Fowler-Sabine formula. It was found that the permanent threshold shift (PTS) contours are typical of noise-induced hearing loss, and are similar to those associated with most kinds of steady-state exposure and show increasing deterioration with duration of impulse noise exposure, but they never reach the asymptote. Great individual variations in threshold shift, particularly at 4000 Hz, expressed in a 23 dB standard deviation from the mean values were observed. The comparison of observed impulse noise-induced PTS with that predicted by the energy concept for steady-state exposure showed that there is no good agreement between observed and predicted data; furthermore, the curve shapes are not similar to one another.

82-1404

**A Model to Describe Community Response to Impulse Noise**

P.D. Schomer
Construction Engrg. Res. Lab., U.S. Army Corps of Engineers, P.O. Box 4005, Champaign, IL 61820,
Noise Control Engrg., 18 (1), pp 5-15 (Jan-Feb 1982)
2 figs, 10 tables, 12 refs

Key Words: Urban noise, Human response

This article summarizes some of the results of a study primarily designed to assess community response to impulse noise (for example artillery, demolition) in comparison with more normal community noise sources, such as fixed wing aircraft, street traffic and neighborhood children. The type of energy model which best describes community response to impulse noise is analyzed. It is concluded that C-weighting offers the best standard measure available to assess impulse noise and that C-weighting DNL is a reasonable community assessment measure. No compelling justification can be found for retaining the present 85 dB sound exposure level (SEL) threshold incorporated in the current National Academy of Science procedures, nor can any compelling justification be found for developing or utilizing some form of impulse correction factor based on the individual SEL level of events.

82-1405

**Time of Day Corrections to Aircraft Noise Assessment Metrics**

W.T. Shepherd
Federal Aviation Admin., Washington, DC, S/V,
Sound Vib., 16 (2), pp 10-12 (Feb 1982) 1 fig, 1 table, 13 refs

Key Words: Aircraft noise, Human response

The evolution of cumulative noise metrics is reviewed emphasizing their inherent added corrections for community noise events occurring in the evening or at night. The intended purpose and efficacy of these corrections in the aircraft noise measurement case are also discussed. The day-night average sound level ($L_{dn}$) is the focus of the discussion. The 10 decibel correction in $L_{dn}$ has only a slight scientific basis and it is unlikely that it has much impact on the distribution of aircraft operations throughout the day. Nevertheless, the implications of a change to some alternate method of rating aircraft noise impact are such that more problems would be created than solved by doing so.

# MECHANICAL COMPONENTS

## ABSORBERS AND ISOLATORS

82-1406

**Vibration Isolation on Floating Floors**

P.A. Nelson
Sound Attenuators Ltd., Eastgates, Colchester, Essex, UK,
Appl. Acoust., 15 (2), pp 97-109 (Mar 1982)
7 figs, 7 refs

Key Words: Vibration isolators, Machinery vibration, Floating floors

An analysis is presented of the noise problem produced when the application of standard acoustic treatment to a roof-mounted diesel generator failed to meet the design criterion. The problem was diagnosed as excessive vibration reaching the building due to the excitation of a resonance of the supporting structure. The resonance responsible was identified as a flexural mode of the partial floating floor installed below the generator set in order to provide a high transmission loss acoustic barrier. A solution to the problem was provided by converting the existing vibration isolation into a compound system. The reasons for the failure of the existing system are analyzed. A simple theory is developed which illustrates that the ratio of machine mass to floating floor mass is the important parameter determining the severity of excitation of floating floor resonance. It is concluded that machines can be safely mounted via vibration isolators onto continuous floating floors provided they have a low mass compared with the floating floor mass and are provided with a low mounted resonant frequency compared with the floating floor resonant frequency.

82-1407

**Two Case Studies in the Use of Tuned Vibration Absorbers on Footbridges**

R.T. Jones, A.J. Pretlove, and R. Eyre
Structures Dept., Royal Aircraft Establishment,
The Structural Engineer, 59B (2), pp 27-32 (June 1981) 10 figs, 3 tables, 6 refs

Key Words: Bridges, Moving loads, Dynamic vibration absorption equipment, Vibration absorption equipment

The work described is part of a research program into ways of reducing pedestrian-induced vibrations of footbridges,

the problem being that these vibrations can cause discomfort to the user. The two case studies presented describe one method by which this has been achieved -- the discrete tuned vibration absorber. Results show that an absorber with a low mass value can achieve very worthwhile reductions in vibration levels. This effect is, however, dependent on optimum damping and accurate tuning of the absorber and on minimum dry friction in the absorber movement.

## BLADES

### 82-1408
**Sudden Loss of Rotor Blade from Wind Power Turbine -- Calculation of Maximax Response Spectra**

B. Akesson and S. Sandstrom
Div. of Solid Mechanics, Chalmers Univ. of Tech., S-41296, Gothenburg, Sweden, J. Sound Vib., 80 (1), pp 81-96 (Jan 8, 1982) 5 figs, 7 refs

Key Words: Rotor blades (turbomachinery), Turbines, Wind turbines, Blade loss dynamics, Maximax response

The maximum response of a linear one-degree-of-freedom system to a transient phase-shifted truncated sinusoidal load is studied. The system represents the nacelle, tower and foundation of a horizontal axis wind power turbine. The load is the horizontal component of the unbalanced centrifugal force from the remaining blade of the turbine rotor when one blade has suddenly broken off (close to the hub). The most dangerous angle of the running rotor at the instant of blade loss is found with respect to different combinations of viscous damping and load duration. Maximax response spectra (envelope spectra) are plotted. A detailed numerical example is given.

### 82-1409
**Torsional Vibrations of Non-Uniform Rotating Blades with Attachment Flexibility**

V.T. Nagaraj and N. Sahu
Helicopter Design Bureau, Hindustan Aeronautics Ltd., Bangalore 560 017, India, J. Sound Vib., 80 (3), pp 401-411 (Feb 8, 1982) 4 figs, 5 tables, 8 refs

Key Words: Blades, Rotor blades (turbomachinery), Rotary wings, Torsional vibration, Finite element technique, Rayleigh-Ritz method, Galerkin method

The torsional vibrations of non-uniform pretwisted rotating blades are studied by using finite element methods based on both the Rayleigh-Ritz and Galerkin formulations. The apparent differences between the matrices obtained from these formulations are explained and, as obtained by using three different orders of elements, results are presented for blades with flexibly attached roots and for a non-uniform blade representative of a bearingless rotor. A parametric study is carried out to resolve a controversy regarding the relative importance of certain terms in the equations of motion of pretwisted rotating blades. In Appendix I, an exact solution is presented for the torsional vibrations of flexibly attached rotating blades with piecewise constant inertia and elastic properties, which serves as a benchmark solution for the finite element results.

## BEARINGS
(Also see Nos. 1339, 1509, 1515)

### 82-1410
**Influence of the Fluid Inertia Forces on the Dynamic Characteristics of Externally Pressurized Thrust Bearings (1st Report, Influence of the Fluid Inertia Forces Generated at the Restricted Part of Externally Pressurized Circular Thrust Bearings with Capillary Restriction)**

Y. Haruyama, T. Kazamaki, and H. Mori
Toyama Univ., 1-1, Nakagawa-Sonomachi, Takaoka, Japan, Bull. JSME, 25 (200), pp 284-290 (Feb 1982) 14 figs, 6 refs

Key Words: Bearings, Thrust bearings, Lubrication, Fluid-inertia forces, Stiffness coefficients, Damping coefficients

The influence of the fluid inertia forces generated at the restricted part on the dynamic characteristics of externally pressurized circular thrust bearings with capillary restriction are investigated. From comparison with the experiment, it may be concluded that the influence on the dynamic characteristics should be considerable when the kinematic viscosity of the lubricant becomes too low, and that the presented analysis yields good predictions for both the bearing stiffness and the damping coefficient in a wide range of designing conditions.

### 82-1411
**Response of a Cylindrical Machine Casing to Oscillatory Bearing Forces**

C.H. Hansen and L.D. Pope
Bolt, Beranek and Newman Inc., Canoga Park, CA 91305, J. Sound Vib., 80 (2), pp 179-192 (Jan 22, 1982) 7 figs, 5 refs

Key Words: Housings, Bearings, Vibration response

An analytical model is developed for the vibration response of a cylindrical machine casing excited by the force arising in a bearing that is assumed to support a rotating shaft. The casing system consists of a bearing housing mounted in a flat circular end cap that is built into a cylindrical casing. The housing is considered to be a rigid trunnion in the center of the end cap (which itself is modeled as a Mindlin plate). The development allows for arbitrary location of the center of mass of the housing and of the plane of action of the exciting force.

**82-1412**

**Improvement of Rolling Bearing Fatigue Life under Debris-Contaminated Lubrication by Decreasing the Crack Sensitivity of the Material**

I. Sugiura, O. Kato, N. Tsushima, and H. Muro
NTN Toyo Bearing Co., Ltd., (511) Kuwana, Japan,
ASLE Trans., 25 (2), pp 213-220 (Apr 1982) 14 figs, 3 tables, 5 refs

Key Words: Rolling contact bearings, Fatigue life, Lubrication

Rolling contact fatigue life under debris- (or foreign particle-) contaminated lubrication is less than one-tenth the life under noncontaminated lubrication when the contaminating debris is hard, large particles (0.1 mm). A small crevasse-type crack initiates at the forward or backward side of a debris particle indentation and grows into fatigue flaking. Relation between heat treatment conditions and the crack sensitivity of the ball bearing steel is investigated. The heat treatment which decreased crack sensitivity increased rolling contact fatigue life significantly not only under debris contaminated lubrication but also under noncontaminated lubrication.

**82-1413**

**The Development and Experimental Evaluation of a New Self-Aligning Thrust and Journal Bearing Arrangement**

M.A. Prohl and O. Tuncel
General Electric Co., Lynn, MA, ASME Paper No. 81-WA/Pwr-1

Key Words: Bearings, Thrust bearings, Journal bearings, Steam turbines, Turbines, Alignment

This paper describes a new bearing casing for the front standard of a steam turbine which carries a journal bearing and thrust bearing with active and inactive tapered-land surfaces. Since initial and operational misalignments of the rotor can adversely affect bearing performance, the bearing casing is supported in a unique self-aligning structure which permits both the journal and the thrust bearings to align themselves with the rotor. Two complete turbine front standards were tested back-to-back to check the overall performance of the self-aligning structure. Both steady state and transient thrust load tests were made. Test results show that the self-aligning feature in the new front standard design provides positive protection against rotor misalignments.

**82-1414**

**Effects of Fluid Inertia and Viscoelasticity on Squeeze Film Bearing Forces at Large Vibration Amplitudes**

J.A. Tichy
Rensselaer Polytechnic Inst., Troy, NY 12181, Wear, 76 (1), pp 69-89 (Feb 1, 1982) 9 figs, 9 refs

Key Words: Squeeze-film dampers, Squeeze-film bearings, Large amplitudes

An approximate analytical solution is presented for squeeze film damper forces, which accounts for the effects of fluid inertia and viscoelasticity in the short bearing case. An earlier exact solution for infinitesimal oscillation amplitudes is extended to finite amplitudes using the Rivlin-Ericksen second-order fluid. The governing equations are linearized using an Oseen-type approximation and the resulting partial differential equation is solved by approximating variable coefficient terms to obtain a periodic solution. Although the method is applicable for arbitrary periodic shaft motion, results are computed for the non-cavitating ($2\pi$) bearing, in which the shaft performs circular centered orbits. Large discrepancies from lubrication theory are found, particularly with regard to phase-shifting (cross-coupling) behavior between the forces and the imposed motion. Results are presented in terms of the Reynolds and Deborah numbers over ranges which are applicable to many practical lubrication problems.

**82-1415**

**Wear Mechanisms in Oscillating Bearings**

Y. Berthier and D. Play
Laboratoire de Mecanique des Contacts, Institut National des Sciences Appliquées de Lyon, 20 avenue Albert Einstein, 69621 Villeurbanne, France, Wear, 75 (2), pp 369-387 (Jan 15, 1982) 15 figs, 2 tables, 10 refs

Key Words: Bearings, Friction, Wear

Surface examination of dry oscillating bearings reveals three different contact zones and indicates that various frictional behaviors take place during the process. The relation between wear and applied conditions such as load and amplitude of oscillation is obscured by the complex behavior of most frictional materials. Studies of initial destruction, transfer and elimination are easier with materials that show simple behavior. Friction and wear are governed by load-carrying third bodies transported in the contact. Transport was confirmed during observation through a hollow glass ring rubbing on a chalk sector. Wear debris motion explains the manner in which geometry modification occurs with time. Circumferential debris transport due to ring motion is modified at the center of the sector where transverse flow takes place. The initial O-shaped sector can change into an $\omega$ configuration. Thus the calculation of wear or of eliminated material must allow for the new $\omega$ shape. The new shape also controls bearing clearance. The effects of load and oscillating motion on wear parameters are presented. More than one wear mechanism can exist in a single contact.

**82-1416**

**Lubricant Effects in Rolling-Contact Fatigue**

C.N. Rowe and E.L. Armstrong
Mobil Res. and Dev. Corp., Paulsboro, NJ 08066, Lubric. Engrg., 38 (1), pp 23-30, 39-40 (Jan 1982) 7 figs, 10 tables, 22 refs

Key Words: Bearings, Fatigue life, Lubrication

Background information leading to the recognition that lubricant chemical factors can affect the fatigue life of bearings is reviewed. This paper describes the sequence of testing in the authors' laboratories to evaluate water-accelerated fatigue, and gives results for an additive which inhibits the deleterious effect of water in a turbine/circulating oil on ball-bearing fatigue. Different additives can function by different mechanisms, and thus it is possible to formulate an oil with additive combinations exhibiting synergism. Additives can also increase the time to fatigue failure with dry oils and greases. Results are presented for an organophosphonate additive showing that the additive functions by depositing a film on the rolling-contact surfaces. Results are given showing that a combination of two additives in different grease technologies provides significant improvements in fatigue life in different test rigs. These new results in greases demonstrate that a careful balance of a multiple additive system is required to provide the maximum antifatigue benefit.

## GEARS

**82-1417**

**A Multi-Purpose Method for Analysis of Spur Gear Tooth Loading**

R. Kasuba, J.W. Egans, R. August, and J.L. Frater
Cleveland State Univ., OH, Rept. No. NASA-CR-165163, 106 pp (Oct 1981)
N82-10401

Key Words: Gears, Spur gears

A large digitized approach was developed for the static and dynamic load analysis of spur gearing. An iterative procedure was used to calculate directly the variable-variable gear mesh stiffness as a function of transmitted load, gear tooth profile errors, gear tooth deflections and gear hub torsional deformation, and position of contacting profile points. The developed approach can be used to analyze the loads, Hertz stresses, and PV for the normal and high contrast ratio gearing. Presently the modeling is limited to the condition that for a given gear all teeth have identical spacing and profiles (with or without surface imperfections).

**82-1418**

**Results of Separating Calculations for Representing Gears as Torsion Oscillation Systems (Ergebnisse von Diskretisierungsrechnungen zur Darstellung der Zahnradgetriebe als Torsionsschwingungssysteme)**

R. Neidhardt
Falkenstein/Vogtl., Maschinenbautechnik, 30 (12), pp 553-559 (1981) 9 figs, 1 table, 4 refs
(In German)

Key Words: Gears, Torsional vibration

For calculation of limit working time of toothings the exact knowledge of real tooth force behavior is important. Accordingly the gear has to be considered as a total system capable of oscillations which also comprehends above all the mass actions of shafts. For this the shaft sections are separated by means of suitable methods.

## FASTENERS

(Also see Nos. 1442, 1579, 1580, 1581, 1582)

**82-1419**

**Finite Element Analysis of the Threaded Connections Subjected to External Loads**

M. Tanaka, K. Hongo, and E. Asaba
Shinshu Univ., 500, Wakasato, Nagano, 380, Japan, Bull. JSME, 25 (200), pp 291-298 (Feb 1982) 16 figs, 1 table, 6 refs

Key Words: Fasteners, Bolted joints, Locsening, Contact stresses, Finite element technique

This paper introduces a numerical method to analyze threaded connections subjected to transverse displacement and flange coupling under an arbitrary type of load. The self-loosening mechanism of the threaded connections and the relation between the axial tension and the external load are discussed.

**82-1420**
**New Data on Fastener Fatigue**
C. Crispell
SPS Technologies, Jenkintown, PA, Mach. Des., 54 (8), pp 71-74 (Apr 22, 1982)

Key Words: Fasteners, Fatigue life

Surprisingly, large-diameter fasteners have lower fatigue strengths than small-diameter fasteners of the same material. New data helps avoid fatigue failures by pinpointing acceptable stress levels for threaded fasteners with diameters up to 5¼ inches.

**82-1421**
**Fluid-Elastic Vibrations of a Slip Joint -- a Model Problem**
S.D. Savkar
General Electric Corporate Res. and Dev., Schenectady, NY, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 127-133, 4 figs, 5 refs

Key Words: Slip joints, Nuclear reactor components, Fluid-induced excitation, Design techniques

As a model for a class of slip joint self-excited vibration problems, the self-excited vibrations of a spring mounted piston in a housing are examined. From the analysis, two key parameters of value in developing a design guide are identified. These parameters appear to govern the neutral stability boundary of this class of problem.

## VALVES
(Also see No. 1473)

**82-1422**
**Transient Analysis of Water Slug Discharge in PWR Safety/Relief Valve Piping**
D.A. Van Duyne, J.S. Hsieh, and D.F. Shave
Stone & Webster Engrg. Corp., Boston, MA, ASME Paper No. 81-WA/FE-31

Key Words: Valves, Piping systems, Transient excitation

The sudden discharge of the water loop seal, which is often present upstream of pressurizer safety and relief valves, creates large momentum and inertia forces on the piping segments downstream of the valve. This paper provides a brief discussion of the commonly available control-volume calculation techniques, a description of the governing equations and a recently developed computer routine for their solution, and a review of results calculated using this method for a typical pressurizer safety and relief valve system.

**82-1423**
**Acoustic Source Properties of Governor Valves**
J.A. Chadha, D.E. Hobson, A. Marshall, D.H. Wilkinson
Ontario Hydro, Toronto, Canada, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 125-138, 12 figs, 7 refs

Key Words: Valves, Piping systems, Sound generation

The experimental and theoretical studies performed to characterize the overall acoustic source properties of governor valves are described. The test rig, the associated instrumentation, the theoretical model for the passive circuit acoustics, and the statistical analysis model for the determination of the acoustic source associated with the governor valve model provide satisfactory results. The limitations of the acoustic source measurement technique and areas requiring further development are identified.

## SEALS

**82-1424**
**A Review of Mechanical Face Seal Dynamics**
I. Etsion

Dept. of Mech. Engrg., Technion - Israel Inst. of Tech., Haifa 32000, Israel, Shock Vib. Dig., 14 (3), pp 9-14 (Mar 1982) 39 refs

Key Words: Seals, Reviews

A literature review of mechanical face seal dynamics is presented; experimental observations and theoretical analyses are summarized. The contribution of various elements of the seal to its dynamic behavior is discussed; the difficulties of analyzing seal dynamics are pointed out.

**82-1425**

**Dynamic Whirl in Well-Aligned, Liquid-Lubricated End-Face Seals with Hydrostatic Tilt Instability**

R. Metcalfe

Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada K0J 1J0, ASLE Trans., 25 (1), pp 1-6 (Jan 1982) 6 figs, 7 refs

Key Words: Seals, Whirling, Journal bearings

Dynamic whirl in well-aligned, fully liquid-lubricated end-face seals is analyzed and tested. As with whirl of journal bearings, seal whirl occurs under lightly loaded conditions -- in this case controlled by balance ratio. The two common seal arrangements are analyzed, including effects of the elastomer secondary sealing elements. Whirling is found to be induced by hydrostatic tilt instability and controlled hydrodynamically. Elastomer effects tend to suppress seal whirl, while seal-ring inertia effects are generally insignificant. Test results support the analysis and give insight into the relative magnitudes of liquid film and elastomer moments with variations of pressure, shaft speed and whirl amplitude.

Key Words: Moorings, Off-shore structures, Water waves, Equations of motion

Multivariate polynomial approximations are considered to the coupled nonlinear mooring forces acting on a vessel moored with multileg moorings. The objective is to yield explicit forms of equations of the low-frequency vessel motions, since the exact mooring forces are known numerically only. Such forms could then be used for analytical solutions of the equations of motion. It is shown that the polynomials lack sufficient generality and accuracy for this purpose, and hence solution of the problem can be considered only by the exact method.

**82-1427**

**Motions of a Vibrating String in the Presence of a Straight Fixed Obstacle (Mouvements Presque-Périodiques d'Une Corde Vibrante en Présence d'un Obstacle Fixe, Rectiligne ou Ponctuel)**

H. Cabannes and A. Haraux

Universite Pierre et Marie Curie, 4 place Jussieu, 75005 Paris, France, Intl. J. Nonlin. Mechanics, 16 (5/6), pp 449-458 (1981) 5 figs, 11 refs

(In French)

Key Words: Strings, Vibrating structures

The plane motions of a vibrating string, fixed at both ends, in the presence of a straight fixed obstacle, parallel to the equilibrium position of the string are considered. The rebound of the string on the obstacle obeys the law of perfect reflection. It is proven that, under rather general conditions, the motion of the string initially at rest, is an almost periodic function of the time. The case of a fixed mass-point obstacle placed on the normal mid-line of the segment joining the fixed ends of the string is considered.

# STRUCTURAL COMPONENTS

## STRINGS AND ROPES

**82-1426**

**Polynomial Approximations to Mooring Forces in Equations of Low-Frequency Vessel Motions**

B.W. Oppenheim and P.A. Wilson

B.W. Oppenheim, Ph.D. & Associates, Inc., Los Angeles, CA, J. Ship Res., 26 (1), pp 16-24 (Mar 1982) 8 figs, 3 tables, 6 refs

## CABLES

**82-1428**

**Dynamic Behavior of a Submarine Cable in a Uniform Sea Flow**

R. Kishimoto and I. Kitazawa

Integrated Transmission Dev. Div., Yokosuka Electrical Communication Lab., Nippon Telegraph and Telephone Public Corp., Take 1-2356, Yokosuka-shi, Kanagawa, Japan, Bull. JSME, 25 (200), pp 204-212 (Feb 1982) 20 figs, 3 tables, 9 refs

Key Words: Cables, Underwater structures, Towed systems, Vortex-induced vibration, Fluid-induced excitation, Vibration measurement

The dynamic behavior of a submarine cable towed in a uniform sea flow was studied through a 1 km cable towing oceanic experiment. The cable form was obtained by using depth data from seven sensor units fixed in the cable at 100 meter intervals, and the straight distances between two supersonic transmitters fixed to both sides of the ship and seven supersonic receivers in the same sensor units. Cable vibration was measured with a 3-axial accelerometer fixed in the cable 150 meters from the cable end.

**82-1429**

**A Three-Dimensional Nonlinear Large-Deflection Model for Dynamic Behavior of Risers, Pipelines, and Cables**

M.M. Bernitsas

Dept. of Naval Architecture and Marine Engrg., Univ. of Michigan, Ann Arbor, MI, J. Ship Res., 26 (1), pp 59-64 (Mar 1982) 5 figs, 15 refs

Key Words: Marine risers, Pipelines, Cables, Underwater structures, Underwater pipelines, Large amplitudes

A comprehensive nonlinear model for the dynamic behavior of marine risers, cables, and pipelines has been developed. Large three-dimensional lateral oscillations are modeled in the local principal, osculating and rectifying planes. Longitudinal extensional oscillations in the local tangential direction are also taken into account. The derived model shows the significance of three-dimensional bending effects and the contribution of the nonlinear terms. Lateral and longitudinal oscillations are coupled due to the curvature and geometric torsion of the centerline of the structure. The model also shows the effects of the external hydrostatic and the internal mud static pressure forces -- which are integrated exactly along the structure -- on the structure's tensile and bending rigidity.

**82-1430**

**Preliminary Design of Mooring Systems**

M.S. Triantafyllou

Dept. of Ocean Engrg., Massachusetts Inst. of Tech., Cambridge, MA, J. Ship Res., 26 (1), pp 25-35 (Mar 1982) 8 figs, 24 refs

Key Words: Moorings, Design techniques

The preliminary design of mooring systems is formulated by separating the quasi-steady solution from the dynamic solution. A multiple time-scale expansion provides the appropriate equations, which are nonlinear for the quasi-steady part and linear space varying for the dynamic part. The fast dynamic solution consists of a fast varying and a slowly varying part with respect to space. An asymptotic solution is obtained by using the WKB method for the fast part, while an approximate expression is derived for the slow part. The resulting solution is simple and can be used to determine the dynamic behavior of complex systems, while permitting an extensive parametric search and the use of spectral techniques. This formulation leads to rational measures of the dynamic performance which, combined with cost considerations obtained from the static solution, permit an optimal selection of the system parameters. An example demonstrates the features of this methodology.

## BARS AND RODS

**82-1431**

**Uniform Real-Variable Asymptotic Approximations for Vibrations of a Rotating Flexible Rod**

W.D. Lakin and A. Nachman

Dept. of Mathematical Sciences, Old Dominion Univ., Norfolk, VA 23508, SIAM J. Appl. Math., 42 (1), pp 77-85 (Feb 1982) 11 refs

Key Words: Rods, Rotating structures, Eigenvalue problems, Flexural vibration

Asymptotic approximations to solutions of the equation for vibrations of a rapidly rotating flexible rod are derived, which are uniformly valid on intervals containing a turning point of the equation. The approximations involve only functions of a real variable, eliminating the need to go into the complex plane to cross a turning point. The uniform approximations are used to study the eigenvalue problem for transverse vibrations of a rotating spoke.

**82-1432**

**The Longitudinal Vibration of Cylindrical Bars with Amplitude-Dependent Modulus**

N.D. Vaughan and R.D. Adams

Dept. of Mech. Engrg., Univ. of Bristol, Bristol BS8 1TR, UK, J. Sound Vib., 80 (1), pp 71-80 (Jan 8, 1982) 6 figs, 1 table, 14 refs

Key Words: Bars, Cylindrical bodies, Longitudinal vibration, Ritz-Galerkin method

The analysis described here was developed to corroborate results obtained in research on a non-destructive test for

cast irons. This analysis is of the Ritz-Galerkin type, and is applied to the longitudinal vibration of cylindrical bars exhibiting a linear change in modulus with amplitude. This theoretical development has been used with experimentally obtained material data for cast irons to predict the change in resonant frequency between two amplitudes for a cast bar. The results are compared with those obtained for tests with bars of identical material.

## BEAMS

(Also see Nos. 1482, 1511)

### 82-1433

### Material Damping of Cantilever Beams

Y. Kume and F. Hashimoto
Dept. of Industrial Engrg., Univ. of Osaka Prefecture, Sakai, Japan, J. Sound Vib., 80 (1), pp 1-10 (Jan 8, 1982) 9 figs, 1 table, 6 refs

Key Words: Beams, Cantilever beams, Material damping

A method for estimating material damping in a cantilever beam is reported. This method shows that the damping can be calculated in terms of the stress distribution functions for each mode of vibration and the damping-stress function. The stress distribution function is determined by the deformation in the cantilever beam as given by the solution for undamped forced vibration. The function obtained by Lazan is employed as the damping-stress function. This approach therefore gives the damping of the beam when incorporated in machine structures undergoing vibration. By using this approach to the cantilever beam problem one theoretically derives the relationship between the loss factor and the maximum stress amplitude in each mode of vibration. It is found that the relationship between the loss factor and the maximum stress amplitude is very similar for each mode of vibration when the modes vibrate with equal stress amplitude.

### 82-1434

### Static and Dynamic Contact Behaviors of Composite Laminates

S.-H. Yang
Ph.D. Thesis, Purdue Univ., 239 pp (1981)
UM 8200751

Key Words: Layered materials, Plates, Beams, Impact force

A simple method has been developed for estimating the contact force and contact duration during an impact. This method has been shown to be quite accurate especially for thicker beams and plates. Static indentation tests were performed to determine the law of contact between steel balls and glass-epoxy and graphite-epoxy laminated composites. Power laws were found adequate for loading, unloading and reloading. A parameter (the critical indentation) was found which can be used to model the unloading with permanent indentation without the need of conducting many unloading tests. It was also demonstrated that the reloading law needs no reloading data to establish once the loading and reloading behaviors are determined. A simple and efficient plate bending element was developed and used to compute the dynamic contact force and response of laminated composites subjected to the impact of an elastic sphere. Evaluative examples were presented for both static loadings and free vibration. The experimental result for impact of a square graphite-epoxy laminate was compared with the finite element solution.

### 82-1435

### Unified Timoshenko Beam Finite Element

A.W. Lees and D.L. Thomas
CEGB South Western Region, Scientific Services Dept., Bedminster Down, Bristol BS1 8AN, UK, J. Sound Vib., 80 (3), pp 335-366 (Feb 8, 1982) 2 figs, 9 tables, 15 refs

Key Words: Finite element technique, Timoshenko theory, Beams

A Timoshenko beam finite element is constructed with an arbitrary number of degrees of freedom. These are the displacement and cross-section rotation at each of two end nodes, together with coefficients of polynomial expansions of the transverse displacement and the shear deformation. Each of these series can be truncated after an arbitrary number of terms, which enables the element to be formulated to achieve any required degree of accuracy. Most of the existing complex beam elements are shown to be special cases of the new formulation. Because only very simple nodal variables are used, the element can be readily incorporated in user-orientated computer programs.

### 82-1436

### A Note on Optimal Design of a Beam with a Mass at Its End

J. Blachut
The Inst. of Physics, Tech. Univ. of Cracow, ul. Podchorażych 1, 30-084 Kraków, Poland, J. Sound Vib., 80 (2), pp 203-208 (Jan 22, 1982) 3 figs, 5 refs

Key Words: Beams, Mass-beam systems, Pontryagin's principle, Optimum design

The problem of determining the optimal cross-sectional area of a column with a tip mass, which is such that volume is minimized under given external load, fixed frequency and geometrical constraints, is investigated by use of the Pontryagin maximum principle.

## CYLINDERS

(Also see No. 1468)

### 82-1437

### Service-Simulation Tests to Determine the Fatigue Life of Outside-Diameter-Notched Thick-Wall Cylinders

J.A. Kapp and J.H. Underwood

Army Armament R&D Command, Large Caliber Weapons Systems Lab., Benet Weapons Lab., Watervliet, NY 12189, Exptl. Mechanics, 22 (3), pp 96-100 (Mar 1982) 6 figs, 4 tables, 8 refs

Key Words: Cylinders, Fatigue life

Simulation specimens were used to model the fatigue behavior of outside-diameter-notched internally pressurized cylinders of alloy steel. Results from continuum mechanics and finite-element analyses are described for use in selection of simulation-test conditions. The effects of notch depth and residual stress on fatigue life are determined from the simulation tests.

### 82-1438

### Vibration of a Group of Circular Cylinders Subjected to Fluid Flow

S. Chen

Components Tech. Div., Argonne Natl. Lab., Argonne, IL, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 75-88, 77 refs

Key Words: Circular cylinders, Cylinders, Tube arrays, Heat exchangers, Nuclear fuel elements, Fluid-induced excitation, Design techniques

Many structural and mechanical components consist of multiple circular cylinders, such as heat exchanger tubes and nuclear fuel bundles. These components are subjected to fluid flow. The fluid flow represents a source of energy that can induce and sustain vibration. In addition, the fluid moving with vibrating structures has an important effect on the dynamic characteristics of the structure. The objective of this paper is to review the dynamics of multiple circular cylinders in stationary fluid, parallel flow and cross flow, and to present general design guides to avoid detrimental vibration and instability.

### 82-1439

### Vortex Shedding Excitation and the Vibration of Circular Cylinders

H.J. Connors

Westinghouse Res. and Dev. Ctr., Pittsburgh, PA, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 47-73, 14 figs, 1 table, 21 refs

Key Words: Circular cylinders, Cylinders, Tube arrays, Fluid-induced excitation, Vortex shedding, Design techniques

A design method is presented for predicting tube vibration caused by vortex shedding. It can be applied to a variety of tube configurations and flow situations. For liquid applications the damping parameter is small, typically about .2, and large vibrations may be predicted when the vortex shedding frequency coincides with a tube natural frequency. For steam condensers the damping parameter is typically about 2000 and vibrations caused by vortex shedding are predicted to be very small. Sample calculations are given to demonstrate the method.

### 82-1440

### Finite, Free Torsional Oscillations of Hollow Circular Cylinders Made of a Mooney Material

A. Ertepinar and A. Gürkök

Dept. of Engrg. Sci., Middle East Technical Univ., Ankara, Turkey, J. Sound Vib., 80 (3), pp 305-313 (Feb 8, 1982) 5 tables, 17 refs

Key Words: Cylinders, Circular cylinders, Torsional vibration

Finite, free torsional oscillations of hollow circular cylinders of arbitrary wall thickness and of arbitrary length are investigated. The material of the cylinder is assumed to be homogeneous, isotropic, elastic and incompressible. The governing differential equations of motion are obtained by the use of

finite elasticity theory. While the exact solution of the problem requires a rather unrealistic body force distribution in the axial direction, it is shown that, in the solutions corresponding to long tubes and hollow disks, the error introduced by ignoring the body force distribution is negligibly small for large wavelengths.

### 82-1441
**A Mechanism for Parallel Flow-Induced Vibrations**
Y.T. Fung
Nuclear Energy Engrg. Div., General Electric Co., San Jose, CA, "Flow-Induced Vibration of Power Plant Components," Pressure Vessels and Piping Conference. ASME Century 2 – Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 65-76, 7 figs, 16 refs

Key Words: Cylinders, Turbulence, Fluid-induced excitation

Vibration characteristics of a cylindrical structure subject to turbulent parallel flows are investigated. Pressure fluctuations from external flows on the surface of the cylinder provide the lateral forces for oscillation motion. Homogeneity of the fluctuating pressure in the turbulent boundary layer of the cylinder is assumed. A mechanism based on a time scale, namely the azimuthal time delay resulting from the small scale nonaxisymmetric perturbations to the pressure field, is proposed. This mechanism is based on the propagation of pressure fronts with the characteristic azimuthal time delay playing an important role in the degree of lateral force concentration, and therefore, in the flow-induced oscillation of the cylinder. In view of the proposed mechanism, the axisymmetric pressure perturbation results in a case of lateral force concentration in which the magnitudes of the resulting forcing function and of the vibration response are the maxima. These characteristics may serve as criteria to predict the upper bound for the vibration response of structures when asymmetric perturbation are present in turbulent parallel flows.

## COLUMNS

### 82-1442
**A Study of Lapped Splices in Reinforced Concrete Columns under Severe Cyclic Loads: Progress Report**
K. Lukose, P. Gergely, and R.N. White
Dept. of Struc. Engrg., Cornell Univ., Ithaca, NY, Rept. No. NSF/CEE-81035, 223 pp (July 1981) PB82-131798

Key Words: Columns, Reinforced concrete, Joints (functions), Cyclic loading

In an investigation of the behavior of overlapped reinforcing rods under high level, inelastic, reversing cyclic loads, 14 tests were conducted on column specimens with No. 6 spliced bars at the corners of surrounding No. 3 stirrups, subjected to combined bending and shear. The relationship between the splice length and the stirrup spacing was studied in detail. The most significant result was that a reasonable level of ductility in splices under combined bending and shear was achieved by providing uniformly spaced stirrups along the splice, and closely spaced stirrups just outside the high moment splice end. An equation for splice design was developed for specimens of the type tested. Experimental results are discussed in terms of load versus displacement, energy absorption, stiffness reduction, main bar strain variation, compression splice behavior, and bond-shear interaction.

## MEMBRANES, FILMS, AND WEBS

### 82-1443
**Propagation and Stability of Non-Linear Waves in Spinning Anisotropic Membrane-Like Disks**
J.L. Nowinski
Mech. and Aerospace Engrg. Dept., Univ. of Delaware, Newark, DE 19711, Intl. J. Nonlin. Mech., 16 (5/6), pp 427-437 (1981) 2 figs, 1 table, 20 refs

Key Words: Membranes, Disks, Rotating structures, Flexural vibration, Wave propagation

The system of two nonlinear coupled differential equations of the second and fourth orders, respectively, governing motions of a rotating anisotropic membrane-like disk, is analyzed under the assumption of a particular form of the transverse deflections. The general equations derived for the stresses are compared with the known particular solutions associated with both a nonlinear purely vibrational mode and nonlinear (and linear) wave propagation in anisotropic and isotropic materials. The stability of motion for a specific mode and a particular choice of temporal perturbation is investigated. General equations obtained for the perturbation parameters are examined in two particular cases.

## PANELS

### 82-1444
**Sound Transmission through a Damped Sandwich Panel**
S. Narayanan and R.L. Shanbhag

Dept. of Appl. Mechanics, Indian Inst. of Tech., Madras - 600036, India, J. Sound Vib., 80 (3), pp 315-327 (Feb 8, 1982) 6 figs, 3 tables, 15 refs

Key Words: Panels, Sandwich structures, Damped structures, Viscoelastic damping, Sound transmission

The sound transmission through an infinite sandwich panel with a constrained viscoelastic damping layer is analyzed. Expressions for the sound transmission loss and the coincidence frequency are derived in terms of the core parameters and incidence pressure angle. Results show that the sandwich panel has better sound transmission characteristics than a homogeneous elastic panel of equivalent weight.

## PLATES

(Also see Nos. 1434, 1443)

### 82-1445

### Vibration and Stability of Annular Plates under Conservative and Non-Conservative Loads

S. Chonan

Dept. of Mech. Engrg., Tohoku Univ., Sendai, Japan, J. Sound Vib., 80 (3), pp 413-420 (Feb 8, 1982) 4 figs, 4 refs

Key Words: Plates, Annular plates, Flutter

This paper deals with the vibration and stability of annular plates elastically restrained against translation and rotation at the edges. The plate is subjected to a horizontal or tangential radial load. Both axisymmetric and non-axisymmetric vibrations are considered. Numerical results are obtained for the plate with free outside and elastically restrained inside edges when the ratio of inner to outer radius is 0·3. The flutter and divergence instability loads are obtained for a range of constraint stiffness parameters of the inside edge and are shown graphically.

### 82-1446

### Vibration and Stability of a Free Circular Plate Subjected to Non-Conservative Loading

Z. Celep

Dept. of Mech. Engrg., Massachusetts Inst. of Tech., Cambridge, MA 02139, J. Sound Vib., 80 (3), pp 421-432 (Feb 8, 1982) 7 figs, 15 refs

Key Words: Plates, Circular plates, Nonconservative forces, Mode shapes

This paper is concerned with the stability and vibration of a completely free circular plate subjected to a non-conservative edge loading. The eigencurves and mode shapes of the plate are obtained for various values of the non-conservativeness parameter. Numerical results are presented for the asymmetrical mode shapes of the plate. Interesting conclusions are drawn from these results, some of which are verified analytically.

### 82-1447

### Axisymmetric Vibrations of a Circular Plate of Linearly Varying Thickness on an Elastic Foundation According to Mindlin Theory

J.S. Tomar and D.C. Gupta

Dept. of Appl. Mech., Univ. of Roorkee, Roorkee 247672, India, J. Sound Vib., 80 (2), pp 281-286 (Jan 22, 1982) 1 fig, 6 refs

Key Words: Plates, Circular plates, Variable cross section, Elastic foundations, Axisymmetric vibrations

Free axisymmetric vibrations of an elastic circular plate of linearly varying thickness on an elastic foundation have been studied on the basis of shear theory. The transverse displacement and local rotation are expressed as an infinite series. The frequencies corresponding to the first two modes of vibrations are obtained for a circular plate with clamped and simply supported edge conditions for various values of the taper constant and the foundation modulus.

### 82-1448

### Free Vibration of Annular Sector Plates with Edges Possessing Different Degrees of Rotational Restraint

M. Mukhopadhyay

Dept. of Naval Architecture, Indian Inst. of Tech., Kharagpur 721 302, India, J. Sound Vib., 80 (2), pp 275-279 (Jan 22, 1982) 1 fig, 4 tables, 8 refs

Key Words: Plates, Annular plates, Boundary condition effects

Results for the natural frequencies of annular sector plates possessing different degrees of elastic restraint along the edges are presented. The analysis is based on a numerical method developed by the author. The functions in the circumferential direction satisfying the boundary conditions along the radial edges, which are required in the analysis, are indicated.

**82-1449**

**Free Vibration of a Simply-Supported Rectangular Plate with a Straight Through-Notch**

K. Nezu
Faculty of Engrg., G[illegible] Kiryu, Gumma, Japan, Bull. JSME, [illegible]-23 (Jan 1982) 16 figs, 1 table, 4 refs

Key Words: Plates, Rectangular plates, Cracked media, Vibration analysis

Free vibration of a simply-supported rectangular plate having a straight notch simulating a through-crack in the plate is analyzed to obtain its eigenvalues and the dynamic stress concentration in the front of the notch. The plate is divided into two parts along the notch and Fredholm integral equations of the first kind are derived for the internal moment and shearing force, using Green functions satisfying the boundary conditions of each part and continuity conditions of deflection and deflection angle of the original plate. The integral equations are transformed into the algebraic equations by the numerical integration and subdomain method, to calculate the eigenvalues and the moment and shearing force distributions. They are numerically calculated with regard to the lower four modes and the effects of the aspect ratio of the plate and the length and location of the notch on them are discussed in detail.

**82-1450**

**A Perturbation Solution of Non-Linear Vibration of Rectangular Orthotropic Plates**

A.K. Niyogi and B.L. Meyers
Bechtel Power Corp., Gaithersburg, MD 20760, Intl. J. Nonlin. Mech., 16 (4/5), pp 401-408 (1981) 3 figs, 2 tables, 12 refs

Key Words: Plates, Rectangular plates, Orthotropism, Nonlinear vibration, Perturbation theory

Classical perturbation theory is applied to the nonlinear dynamic response of orthotropic plates. Expressions are derived for the ratio of nonlinear to linear frequency, membrane stress, and the ratio of the maximum total stress to the maximum bending stress. Where possible the analysis is compared to other available numerical solutions, and excellent agreement is shown.

**82-1451**

**Bounds for Eigenfrequencies of a Plate with an Elastically Attached Reinforcing Rib**

D.W. Fox and V.G. Sigillito
Appl. Physics Lab., Johns Hopkins Univ., Johns Hopkins Rd., Laurel, MD 20810, Intl. J. Solids Struc., 18 (3), pp 235-247 (1982) 2 figs, 9 tables, 15 refs

Key Words: Plates, Rectangular plates, Eigenvalue problems

We give rigorous upper and lower bounds to frequencies of vibration of a thin rectangular elastic plate with a variable length reinforcing rib bonded to it along a portion of a center line of the plate. The intent of this study is to demonstrate by a relatively simple but realistic example how the lower bound method can be used effectively for composite structures and to show that the method can be applied much more widely.

**82-1452**

**Axisymmetric Vibrations of Annular Sandwich Plates of Linearly Varying Thickness**

A.P. Gupta and M. Jain
Dept. of Math., Univ. of Roorkee, Roorkee 247672, India, J. Sound Vib., 80 (3), pp 329-337 (Feb 8, 1982) 4 figs, 2 tables, 7 refs

Key Words: Plates, Annular plates, Sandwich structures, Variable cross section, Flexural vibration, Axisymmetric vibration

Free axisymmetric transverse vibrations of annular sandwich plates of linearly varying thickness are considered. Equations of motion are derived by Hamilton's principle and solved by a cubic spline technique. Numerical results are obtained for the first four normal modes of vibration.

**82-1453**

**Green's Functions for Torsional Body Force Problems of an Elastic Thick Infinite Plate and Their Application (A Finite Solid Cylinder Twisted by Rigid Chucks)**

H. Hasegawa
Dept. of Mech. Engrg., Faculty of Engrg., Meiji Univ., Higashimita 1-1-1, Tama-ku, Kawasaki-city, Japan, Bull. JSME, 25 (199), pp 9-15 (Jan 1982) 9 figs, 10 refs

Key Words: Plates, Torsional excitation, Green function

The principal objectives of this paper are to show a general method of solution for torsional body force problems of an

elastic thick infinite plate, Green's functions for the torsional body force problems mentioned above, and a numerical method of solution for elastic problems of a circular solid finite length cylinder twisted by a pair of axisymmetric rigid chucks. Green's functions shown in the paper are defined as solutions to the elastic problem of an infinite thick plate subjected to torsional body forces acting on a circle in the interior of the plate. The numerical method for solid cylinders is an application of Green's functions shown in the paper. That is, solutions to the solid cylinder are constructed by Green's functions for torsional body force problems of the thick plate. Numerical examples for the problem of the solid cylinder are given.

**82-1454**

**Steady/Oscillatory, Supersonic/Hypersonic Inviscid Flow Past Oscillating Wings and Wedge Combinations at Arbitrary Angles of Attack**

E.V. Youroukos

Naval Postgraduate School, Monterey, CA, Master's Thesis, 182 pp (June 1981)

AD-A107 438

Key Words: Plates, Perturbation theory, Aircraft wings

The perturbation method proposed by Professor Hui is described. The method gives exact solutions for the perturbed flow over both sides of a flat plate which is oscillating with small amplitude and frequency at large angles of attack in steady supersonic/hypersonic inviscid flow provided that the shock remains attached. Using the strip theory concepts these solutions are extended to study the dynamic stability in pitch of a flat, periodically oscillating wing arbitrary planform shape, at large angles of attack. Finally, Hui's perturbation method is extended on a stationary wedge.

**82-1455**

**Finite Element Analysis of Magnetoelastic Plate Problems**

K.-Y. Yuan

Ph.D. Thesis, Cornell Univ., 249 pp (1981)

UM 8129705

Key Words: Plates, Magnetoelastic vibrations, Finite element technique

This thesis presents an integrated study of magnetoelasticity problems for thin nonferrous conducting plates. Three phases of the study have been emphasized: theoretical modeling of interaction problems, finite element eddy current calculations for rigid conducting plates, and finite element numerical studies of coupled magnetoelastic problems. Experimental results by others and analytical solutions for limiting cases have been used to verify the numerical results obtained at each stage of the investigation. The Fortran programs developed for each part of the study are also described.

**82-1456**

**Non-Linear Vibrations of Elastic Plates Subjected to Transient Pressure Loading**

J.R. Coleby and J. Mazumdar

Dept. of Appl. Math., The Univ. of Adelaide, Adelaide, South Australia, Australia, J. Sound Vib., 80 (2), pp 193-201 (Jan 22, 1982) 3 figs, 1 table, 13 refs

Key Words: Plates, Nonlinear vibration, Large amplitudes, Transient excitation, Step functions, Periodic excitation

The large amplitude vibrations of elastic plates of arbitrary plan form subjected to transient pressure loading are analyzed in a relatively simple fashion by using the Berger method in conjunction with the iso-amplitude contour lines method. The analysis provides for both clamped and simply supported edge conditions. By way of illustration, the large amplitude response of elliptical plates under various types of dynamic loading; namely a step function, a sinusoidal pulse and an N-wave, is investigated and the results are presented graphically. Some comparison is made with previously obtained results for circular plates, as available in the literature.

**82-1457**

**Response of a Plate and Elastic Half-Space to Harmonic Waves**

W.L. Whittaker and P. Christiano

Dept. of Civil Engrg., Carnegie-Mellon Univ., Pittsburgh, PA, Earthquake Engrg. Struc. Dyn., 10 (2), pp 255-266 (Mar-Apr 1982) 10 figs, 1 table, 14 refs

Key Words: Plates, Elastic half-space, Seismic waves, Harmonic excitation

Analytical results are presented for the dynamic interaction of an elastic flexural plate and an elastic half-space subjected to harmonic seismic waves. Displacements and contact stresses are presented for square, massless plates having a practical range of flexural stiffness and subjected to incident waves oriented parallel to either an edge or a diagonal of the plate. The behavior of massive plates is also briefly discussed;

such plates exhibit additional resonances higher than those normally associated with the motion of a rigid mass.

## SHELLS

(Also see No. 1471)

### 82-1458

**Influence of Initial Geometrical Imperfections on Vibrations of Axially Compressed Stiffened Cylindrical Shells**

J. Singer and J. Prucz

Dept. of Aeronautical Engrg., Technion-Israel Inst. of Tech., Haifa, Israel, J. Sound Vib., 80 (1), pp 117-143 (Jan 8, 1982) 9 figs, 3 tables, 20 refs

Key Words: Shells, Cylindrical shells, Stiffened shells, Geometric imperfection effects, Vibration response

The vibrations of stiffened cylindrical shells having axisymmetric or asymmetric initial geometrical imperfections and axial preload are analyzed. The analysis is based on a solution of the von Karman-Donnell nonlinear shell equations, an exact solution of the compatibility equation, and a first order approximation by the Galerkin method of the equilibrium equation. The stiffeners are closely spaced and smeared stiffener theory is employed. The results of an extensive parametric study carried out on shells similar to those used in vibration and buckling tests show that stiffening of the shell will lower the imperfection-sensitivity of its free vibrations, but the decrease depends on the type of stiffening (stringers or rings), the mode shapes of the vibration and the imperfection, the stiffener strength and eccentricity. The imperfection-sensitivity decrease, caused by the stiffeners, is greater for vibration mode shapes with high imperfection-sensitivity than for other vibration mode shapes.

### 82-1459

**Influence of Initial Geometric Imperfections on Vibrations of Thin Circular Cylindrical Shells**

L. Watawala

Ph.D. Thesis, Univ. of Massachusetts, 105 pp (1981) UM 8201413

Key Words: Shells, Cylindrical shells, Initial deformation effects, Vibration response

The influence of initial out-of-round geometric imperfections on the vibrations of a right circular cylindrical shell is studied. The analysis is based on a solution of the nonlinear large deflection shell equations using the Galerkin method and the method of averaging. The initial geometric imperfections of the shell are modeled with simple trigonometric functions. Both the free and forced vibrations are presented. As an extension of the study the shell is analyzed when it is completely filled with an incompressible liquid.

### 82-1460

**Response of Containment Vessels to Explosive Blast Loading**

R.R. Karpp, T.A. Duffey, and T.R. Neal

Los Alamos Scientific Lab., NM, 31 pp (June 1980) LA-8082

Key Words: Containment structures, Shells, Explosion effects

The response of steel containment vessels to the blast loading produced by the detonation of high explosives is investigated by experiments, computations, and analysis. The vessels are thin-wall shell structures that are nearly spherical. All explosive charges are solid spheres, centrally initiated and centrally positioned within the vessels. Most of the work concerns vessels that contain, in addition to the explosive charge, air at ambient or reduced pressures. A scaling law that relates the first maximum strain occurring in the vessel wall to other relevant parameters is derived and shown to correlate the experimental data. One-dimensional, Lagrangian, finite-difference calculations are used to study the blast phenomenon and the details of the loading pulse applied to the vessel wall. The results are verified by comparisons with pressure gauge records.

## PIPES AND TUBES

(Also see Nos. 1429, 1438, 1439, 1495, 1560)

### 82-1461

**Transition to Turbulence in a Pulsatile Pipe Flow. Part I, Wave Forms and Distribution of Pulsatile Velocities near Transition Region**

M. Ohmi, M. Iguchi, and I. Orahata

Osaka Univ., Yamadaoka 2-1, Suita, Osaka, Japan, Bull. JSME, 25 (200), pp 182-189 (Feb 1982) 14 figs, 1 table, 26 refs

Key Words: Pipes (tubes), Fluid-induced excitation

Pulsatile flow in a circular pipe can be characterized by three parameters; i.e., the dimensionless frequency, the time-averaged Reynolds number, and the velocity amplitude ratio.

Here by changing the time-averaged Reynolds number, velocity measurements were made by means of a hot wire anemometer. From output signals of pulsatile velocity the flows near the transition region were classified into the following three types: laminar flow, disturbed flow, and turbulent flow. The distributions of oscillatory and time-averaged axial velocity components in each type of flow were characterized with respect to time-averaged Reynolds number.

### 82-1462
### Critical Reynolds Number in an Oscillating Pipe Flow

M. Ohmi and M. Iguchi
Osaka Univ., Yamadaoka 2-1, Suita, Osaka, Japan,
Bull. JSME, 25 (200), pp 165-172 (Feb 1982) 6 figs, 26 refs

Key Words: Pipes (tubes), Fluid-induced excitation

A previous investigation revealed that, when turbulent bursts occur, the instantaneous velocity distribution and friction factor in an oscillating pipe flow are represented by the well-known 1/7 power law and by the turbulent quasi-steady values, respectively. These facts suggest that the mechanism of generating turbulence in an oscillating pipe flow is similar to that in a steady flow. An evaluation method of the critical Reynolds number is proposed by assuming that the generation region of turbulence is the same as that in a steady flow. The estimated results agreed well with the experimental values.

### 82-1463
### Vibration of Heat Exchanger Tube Bundles in Liquid and Two-Phase-Cross-Flow

M.J. Pettigrew and D.J. Gorman
Atomic Energy of Canada Ltd., Chalk River Nuclear Labs., Chalk River, Ontario, Canada, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 89-110, 11 figs, 2 tables, 11 refs

Key Words: Tube arrays, Heat exchangers, Fluid-induced excitation, Design techniques

Heat exchangers must be analyzed at the design stage to avoid flow-induced vibration problems. This paper presents information required to formulate flow-induced vibration excitation mechanisms in liquid and two-phase cross-flow. Three basic excitation mechanisms are considered: namely, fluidelastic instability, periodic wake shedding, and response to random flow turbulence. The vibration excitation information is deduced from vibration response data for various types of tube bundles.

### 82-1464
### Fluidelastic Vibration of Cylinder Arrays in Axial and Cross Flow -- State of the Art

M.P. Paidoussis
Dept. of Mech. Engrg., McGill Univ., Montreal, Quebec, Canada, "Flow-Induced Vibration Design Guidelines," Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engrg., Solar Energy Divisions. Denver, CO, June 21-25, 1981. ASME PVP-52. P.Y. Chen, ed., pp 11-46, 19 figs, 115 refs

Key Words: Tube arrays, Fluid-induced excitation, Heat exchangers, Nuclear fuel elements, Design techniques

This paper provides a critical assessment of the state of the art for flow-induced vibrations of cylinder arrays in cross and axial flow. A short historical review highlights the milestone contributions which advanced our understanding of the flow-induced vibration phenomena involved and/or our predictive ability.

### 82-1465
### Natural Frequencies of Finned Heat Exchanger Tubes

U. Bolleter and R.D. Blevins
Lab. for Vibrations and Acoustics, Sulzer Bros. Ltd., 8401 Winterthur, Switzerland, J. Sound Vib., 80 (3), pp 367-371 (Feb 8, 1982) 2 figs, 2 tables, 3 refs

Key Words: Tubes, Heat exchangers, Flexural vibration, Natural frequencies

The heat transfer of heat exchanger tubes is often enhanced by rolling external fins on to the tubes. These fins contribute to both the mass and the stiffness of the tubes. Calculations of the bending natural frequencies of finned tubes with only the mass contribution considered lead to values which are up to 10% lower than experimental values. A simple correction is derived to account also for the stiffening effect of the fins. With this correction good agreement with experiments is obtained.

**82-1466**

**Vibration of Tubes in a Once-Through Steam Generator During Steady State and Transient Power Operation**

J.C. Simonis and L.H. Bohn

Southwest Res. Inst., San Antonio, TX, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference, ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 109-123, 15 figs, 1 table, 2 refs

Key Words: Tube arrays, Boilers, Nuclear power plants, Fluid-induced excitation, Vibration measurement, Experimental test data

The vibratory response of four tubes in the B loop of the once-through steam generator (OTSG) has been measured at the Oconee 2 nuclear power station during steady-state and transient plant operation. The responses of the tubes were measured by biaxial accelerometers installed in the upper span of three tubes adjacent to a missing lane of tubes (open lane) and a biaxial accelerometer installed in one tube lane towards the interior of the tube bundle (off-lane). The response of the tubes changed during both steady-state and transient test conditions. The shift in the fundamental response frequency of the measured tubes responded to changes in the primary system temperature and power level. The amplitude change was more significant with a power increase than with the temperature increase during heatup. The maximum steady state amplitude of 12 mils rms was reached at near 75% power. The response of the tubes was evaluated during a variety of operating transients. The maximum measured response occurred during the reduction from four to three main reactor coolant pumps at 75% power. The maximum response was 55 mils peak-to-peak.

**82-1467**

**Fluidelastic Vibration of Tube Arrays Excited by Nonuniform Cross Flow**

H.J. Connors

Westinghouse R&D Ctr., Pittsburgh, PA, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference, ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 93-107, 13 figs, 4 refs

Key Words: Tube arrays, Heat exchangers, Wind tunnel testing, Critical speeds, Fluid-induced excitation

Flow fields with highly nonuniform velocity distributions exist in many types of tubular heat exchangers. This investigation is concerned with nonuniform flow in the transverse direction created, for example, by inlet nozzle impingement plates. The impingement plate causes a high velocity skimming flow between the tube bundle and shell. Wind tunnel experiments were conducted using model tube arrays subjected to idealized skimming flow to identify and characterize the mechanism that has caused tube damage in heat exchangers.

**82-1468**

**Unsteady Fluid Dynamic Force on Tube Bundle and Its Dynamic Effect on Vibration**

H. Tanaka and S. Takahara

Second Experiment Lab., Nagasaki Tech. Inst., Tech. Headquarters, Mitsubishi Heavy Industires, Ltd., Nagasaki, Japan, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 77-92, 25 figs, 2 tables, 11 refs

Key Words: Tube arrays, Cylinders, Critical speeds, Fluid-induced excitation

Unsteady fluid dynamic forces acting on vibrating cylinders are considered in this paper. The unsteady fluid dynamic forces comprise the inertia forces due to the added mass of fluid, damping forces of fluid in phase to the cylinder vibrating velocity, and stiffness forces proportional to cylinder displacements. Furthermore, considering the influences of neighboring cylinder vibrations, ten kinds of unsteady fluid dynamic forces are considered to act on a cylinder in a cylinder bundle. Model tests were conducted to measure the forces. Equations of motion for cylinders were deduced, and the critical velocities were calculated with the measured unsteady fluid dynamic forces. Critical velocity tests were also conducted with cylinders that were supported with elastic spars. The critical velocities calculated with unsteady fluid dynamic forces were in agreement with the test results.

**82-1469**

**Turbulence as Excitation Source in Staggered Tube Bundle Heat Exchangers**

Y.N. Chen

Sulzer Brothers, Ltd., Winterthur, Switzerland, "Flow-Induced Vibration of Power Plant Compo-

nents," The Pressure Vessels and Piping Conference, ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 45-63, 11 figs, 1 table, 3 refs

Key Words: Tube arrays, Heat exchangers, Turbulence, Power plants (facilities), Fluid-induced excitation

The role of turbulence as an excitation source in staggered tube bundles is investigated on models with various spacing ratios. It is found that turbulence plays an important role only in narrowly spaced tube bundles in which jet instability, jet switch, or wake swing without vortex shedding is a main excitation source. Turbulence is of a broad-band nature, the intensity of which increases with the flow traveling downstream, and can excite the tube bundle to strong vibrations at high flow rates. If the tube spacings are large, having Karman vortex shedding as a main excitation source, turbulence remains weak throughout the entire tube bundle.

**82-1470**

**The Effects of Artificially Induced Up-Stream Turbulence on the Liquid Cross-Flow Induced Vibration of Tube Bundles**

D.J. Gorman

Dept. of Mech. Engrg., Univ. of Ottawa, Ottawa, Canada, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 33-43, 5 figs, 1 table, 5 refs

Key Words: Tube arrays, Heat exchangers, Vortex shedding, Power plants (facilities), Fluid-induced excitation

It is generally accepted that vortex shedding is likely to be a serious cause of tube bundle vibration at the inlet and second row tubes only, for bundles subjected to liquid cross-flow. A rather extensive series of tests were conducted during which the effect on this vibration of up-stream screens and grids was explored. Bundles which normally had inlet vortex resonances were utilized for the tests. It was anticipated that the flow irregularities due to the upstream grids and screens might prohibit the formation of vortices on the inlet tubes. It was found that relatively fine mesh screens had essentially no effect upon the tube vibration. The situation with regard to coarse grids was quite different. It was found that some grid configurations were capable of sufficiently changing the turbulent character of the approaching fluid to greatly reduce the inlet tube vibration amplitudes. It is postulated that the reduction is due to the change in the turbulence spectrum of the fluid and the accompanying inability of the fluid to form regular correlated vortex shedding patterns on the tubes.

**82-1471**

**A Comprehensive Approach to Avoid Vibration and Fretting in Shell-and-Tube Heat Exchangers**

M.J. Pettigrew and P.L. Ko

Atomic Energy of Canada Ltd., Chalk River Nuclear Labs., Chalk River, Ontario, Canada, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 1-18, 14 figs, 1 table, 15 refs

Key Words: Tube arrays, Heat exchangers, Power plants (facilities), Fluid-induced excitation

A comprehensive approach is outlined to avoid vibration and fretting-wear problems in shell-and-tube heat exchangers. The approach consists of avoiding large vibration amplitudes due to excitation mechanisms such as fluid-elastic instability and periodic wake shedding resonance while making sure that low amplitude vibrations due to other sources do not cause excessive tube damage. A typical vibration analysis involves calculating the tube vibration amplitudes, estimating impact forces between tube and tube-support, and predicting fretting-wear damage from experimental data relating fretting-wear to impact forces. Design data on fluidelastic instability and periodic wake shedding in liquid flow are given. Fretting-wear predictions are outlined by an example.

**82-1472**

**Vibration Testing of a Straight Tube Type Steam Generator for FBR**

K. Kobatake, M. Suzuki, A. Koishikawa, and T. Hashimoto

Engrg. Dept., Nuclear Systems Div., Kawasaki Heavy Industries, Ltd., Tokyo, Japan, "Flow-Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 19-31, 20 figs, 5 tables, 14 refs

Key Words: Tube arrays, Vibration tests, Supports, Power plants (facilities), Fluid-induced excitation

This paper presents experimental and theoretical results for tubes vibrating in air and stationary water. The objective was to obtain the information for design of a FBR steam generator. It is mainly concerned with the effect on frequency, damping, and dynamic response of varying the span of the tube supports, as well as introducing tension in the tubes.

**82-1473**

**Fluid Transient Analysis in Pipelines with Nonuniform Density**

S.W. Webb and J.L. Caves

Gilbert/Commonwealth, Jackson, MI, ASME Paper No. 81-WA/FE-29

Key Words: Pipelines, Valves, Transient excitation

A fluid transient in a system with steady nonuniform liquid density can be analyzed by a single density computer program by modification of the input parameters. These changes allow the program to solve the correct characteristic equations with appropriate initial and boundary conditions. The applicability of the approach has been demonstrated by a transient analysis of a reservoir, pipeline, valve problem and comparing the results.

**82-1474**

**Flow-Induced Motions of Multiple Risers**

T. Overvik, G. Moe, and E. Hjorth-Hansen

Norwegian Inst. of Tech., Trondheim, Norway, ASME Paper No. 81-WA/FE-26

Key Words: Pipes (tubes), Marine risers, Vortex-induced vibration

Vortex-induced and galloping vibrations of flexible risers in steady, uniform currents have been investigated. The cross sections consisted of a bundle of pipes tied together to form a so-called multiple production riser. The tests have been carried out in a wind tunnel at subcritical Reynolds numbers, using spring mounted sectional models.

## DUCTS

(Also see No. 1544)

**82-1475**

**Hydrodynamic Shock in a Rectangular Duct Theoretical Evaluation of Pressure Force Exerted on Duct Bend**

A.H. Warren

American Electric Power Serv. Corp., New York, NY, ASME Paper No. 81-WA/FE-13

Key Words: Ducts, Rectangular ducts, Hydrodynamic excitation, Shock wave propagation

A hydrodynamic shock traveling through the bend of a rectangular duct is investigated. An analytical-numerical technique for the evaluation of the flow field in a two-dimensional space is introduced. The resulting pressure distribution is used to evaluate the pressure force exerted by the pressure wave on the bend. Comparison between a one-dimensional flow model and the present two-dimensional solution is made.

**82-1476**

**Acoustic Model Power Distribution in a Duct at High Frequencies**

S.M. Baxter

Inst. of Sound and Vib. Res., Southampton Univ., UK, Rept. No. ISVR-TR-111, 42 pp (Apr 1981)

PB82-139064

Key Words: Ducts, Acoustic absorption, Measurement techniques

The work described in this report represents part of a project which is an experimental and theoretical investigation of the distribution of acoustic power among the modes of an acoustic duct. The duct forms part of an absorber test facility. The experiment is intended to test an assumption that the sound power in the duct is equally distributed among the propagating acoustic modes. The report is essentially a progress report, and covers the theoretical basis for the measurement technique.

## BUILDING COMPONENTS

**82-1477**

**Earthquake Resistant Structural Walls -- Coupled Wall Tests**

K.N. Shiu, J.D. Aristizabal-Ochoa, G.B. Barney, A.E. Fiorato, and W.G. Corley

Construction Tech. Labs., Portland Cement Assn., Skokie, IL, Rept. No. NSF/CEE-81034, 153 pp (July 1981)

PB82-131954

Key Words: Walls, Seismic design, Earthquake resistant structures

In the development of earthquake resistant, reinforced concrete walls, two one-third scale, six-story coupled wall specimens were tested under incremental cyclic loadings. A lightly coupled system which damaged early was first tested and then retested with the damaged coupling beams replaced by stiffer and stronger beams. The heavy coupling beams between walls caused the system to behave as a single isolated wall, and the coupling beams yielded immediately before and after the yielding of the walls. An analytical model was developed to simulate experimental results and was used to calculate the load versus deflection relationship of the coupled wall system. Using this model, inelastic shear action in the walls was found to be a significant factor in the analysis of a lightly coupled system. In heavily coupled systems, use of the model indicated that redistribution of shear and moment between walls was significant, and that interaction of axial and flexural forces is the most important factor to consider in calculating behavior of heavily coupled systems.

**82-1478**

**Inelastic Behavior and Design of Earthquake Resistant Coupled Walls**

M. Saatcioglu

Ph.D. Thesis, Northwestern Univ., 300 pp (1981)
UM 8124997

Key Words: Walls, Seismic design, Earthquake response, Earthquake resistant structures, Computer programs

The dynamic inelastic response of coupled walls subjected to earthquake excitations was investigated. A parametric investigation was conducted on the effects of selected structural and ground motion parameters. A design procedure and sample design aids were developed for earthquake resistant coupled walls, on the basis of nonlinear dynamic analysis. A comparison of experimental data for a small-scale coupled wall model tested on an earthquake simulator and results of an analysis of the same structure using the analytical procedure employed in this investigation was made. Results show good agreement.

**82-1479**

**Earthquake Resistant Structural Walls -- Tests of Walls With and Without Openings**

K.N. Shiu, J.I. Daniel, J.D. Aristizabal-Ochoa, A.E. Fiorato, and W.G. Corley

Construction Tech. Labs., Portland Cement Assn., Skokie, IL Rept. No. NSF/CEE-81033, 125 pp (July 1981)
PB82-131947

Key Words: Walls, Seismic design, Earthquake resistant structures, Opening-containing media, Windows

The effects of structural wall window openings on strength, deformation capacity, and energy dissipation capacity were determined and evaluated. Two one-third scale, six-story wall specimens were subjected to inelastic load reversals representing severe earthquake forces exerted by double acting hydraulic rams, located on both sides of the wall specimens, and applied to the top of each wall. The specimens were designed of earthquake resistant reinforced concrete wall elements in coupled wall systems based on the 1976 Uniform Building Code. The loading was calculated using a modified DRAIN two-dimensional computer program with two actual earthquake records used as input ground motion data.

**82-1480**

**Studies of Earthquake Resistant Masonry Shear Walls**

A.-H. Salim

Ph.D. Thesis, Univ. of Cincinnati, 159 pp (1981)
UM 8201252

Key Words: Walls, Masonry, Earthquake resistant structures

The notion of confining the critical reaction corners of shear walls subjected to cyclic load has been the subject of many investigations. In 1974 the first experiment of confinement, steel plates in mortar joint of masonry walls, was conducted. Although this method improved the wall behavior regarding load and deformation capacities, its use remains impractical due to expensive labor and material costs. Inclusion of continuous helical steel wire for providing the needed confinement have been used in this project. A preliminary experiment was designed to test concrete block prisms under uniaxial compressive force. The main objective here was to find the effect of confinement reinforcement on the ultimate capacity of concrete block masonry prisms. The resulted optimum confinement reinforcement was then used in the reaction corners of partially grouted masonry concrete block cantilever walls. The parameters were confinement, vertical and horizontal reinforcements. Two unreinforced walls were also tested. Results of the experiments carried out in this project have been plotted. They are axial compressive load versus axial deformation for the prisms and lateral load versus lateral deformation (hysteresis loop) for the cantilever walls.

# DYNAMIC ENVIRONMENT

## ACOUSTIC EXCITATION

(Also see Nos. 1356, 1399, 1507, 1540, 1561)

### 82-1481
**Seismic Safety of Reinforced Concrete Members and Structures**

H. Banon and D. Veneziano
Massachusetts Inst. of Tech., Cambridge, MA, Earthquake Engrg. Struc. Dyn., 10 (2), pp 179-193 (Mar-Apr 1982) 13 figs, 1 table, 23 refs

Key Words: Structural members, Reinforced concrete, Concretes, Earthquake response, Seismic response, Probability theory

Based on cyclic load tests of large-scale reinforced concrete elements and assemblages, a probabilistic model of member failure is developed. The model gives the probability of survival at time t as a functional of damage ratio and dissipated energy up to t. After extension to multivariate survival of several members with correlated resistance, the model is used to calculate the safety of reinforced concrete frames subjected to given input motions. Results are in terms of the probability of local failures and of no failure anywhere in the system.

### 82-1482
**Incremental Time-Space Finite Strip Method for Non-Linear Structural Vibrations**

Y.K. Cheung and S.L. Lau
Dept. of Civil Engrg., Univ. of Hong Kong, Hong Kong, Earthquake Engrg. Struc. Dyn., 10 (2), pp 239-253 (Mar-Apr 1982) 7 figs, 5 tables, 13 refs

Key Words: Periodic response, Finite strip method, Harmonic balance method, Structural response, Beams

Based on an incremental Hamilton's principle a versatile and systematic computer method for analyzing nonlinear structural vibrations is developed in this paper. The essence of the proposed method can be regarded as an incremental harmonic balance method associated with a finite strip procedure in the time-space domain. Only linearized equations in terms of frequency increment, amplitude increments, etc. have to be formulated and solved in each incremental step. This method is applicable to highly nonlinear problems and may be generalized to related nonlinear periodic structural motions such as dynamic stability, flutter and some motions of a rotating body, etc. To show the effectiveness and versatility of this method, a typical time-space finite strip for beam problems is worked out and examples for a wide variety of vibration problems including free and forced vibrations, super- and sub-harmonic resonances, and complicated phenomena such as internal resonance are computed. Comparisons with previous results are also made.

### 82-1483
**An Exploratory Study into the Prediction of Low Frequency Traffic Noise**

G.H. Hollingworth and D.A.M. Gilbert
Main Roads Dept., GPO Box 1412, Brisbane 4001, Queensland, Australia, Appl. Acoust., 15 (2), pp 79-96 (Mar 1982) 4 figs, 6 tables, 24 refs

Key Words: Traffic noise, Noise prediction

An exploratory study to develop equations for the prediction of low frequency traffic noise scales (from traffic parameters) is described. Summaries of noise and traffic measurement procedures are documented and the results of data analysis presented. The equations indicate the large contribution made to low frequency noise levels by heavy vehicles. The implication of this for lorry nuisance is discussed. Broad-band scales are shown to be reasonable surrogates for most, but not all, narrow-band low frequency effects. A method for determining low frequency scales using simple instrumentation is described.

### 82-1484
**Diffraction of Spherical Pulses by a Circular Cylinder**

C.-C. Ku
Ph.D. Thesis, Cornell Univ., 138 pp (1981)
UM 8129621

Key Words: Wave diffraction, Sound waves, Cylinders

This investigation was motivated by recent development of nondestructive evaluation of flaws and cracks in materials, and the longstanding problem of detecting submerged elastic structure by sound waves. In both cases, ultrasonic pulses are transmitted through the medium and are reflected or diffracted by an obstacle. By recording and analyzing the diffracted signals, one tries to determine the location, geometry and material characteristics of the obstacle. Since a mathematical solution for the inverse scattering problem is still not available, most of the analyses are based on the known results of direct scattering by bodies of simple geometry. Among the canonical problems of scattering, the solu-

tion for the diffraction of transient spherical pulses by a long circular cylinder as investigated in this thesis has not been reported in literature.

**82-1485**

**The Forced Vibrational Response of a Rectangular Parallelepiped with Rigid-Lubricated Boundaries**

E.v.K. Hill and D.M. Egle

School of Aerospace, Mech. and Nuclear Engrg., The Univ. of Oklahoma, Norman, OK 73019, J. Sound Vib., 80 (1), pp 61-69 (Jan 8, 1982) 6 figs, 8 refs

Key Words: Rectangular bodies, Forced vibration, Acoustic emission, Normal modes

The Green function for a rectangular parallelepiped with rigid-lubricated boundaries is developed by a normal mode approach, the free vibration solutions being used. Explicit solutions are presented for a concentrated impulse, which serves as a model for an acoustic emission stress wave, and for a concentrated step force. Numerical results for short times show good agreement with the infinite space solution. Analogous solutions are developed for the inverse boundary conditions.

**82-1486**

**The Underwater Acoustic Signature of a Nuclear Explosion at the Ocean Surface**

T.C. Bache, T.G. Barker, M.G. Brown, K.D. Pyatt, and H.J. Swanger

Systems Science and Software, La Jolla, CA, Rept. No. SSS-R-80-4586, VSC-TR-81-24, 32 pp (July 1980)

AD-A107 359

Key Words: Underwater explosions, Nuclear explosions, Acoustic signatures

The gross spectral character and duration of the acoustic wave signature of a nuclear explosion near the ocean surface is estimated by constructing theoretical pressure-time histories, using models for the explosion and wave propagation. The explosion is assumed to have a yield of 1 KT and the nominal range is 6600 km. The frequencies of interest are rather low, 50 Hz and less, so absorption is small and the estimates of spectral character and duration essentially decouple. The spectrum depends almost entirely on the source characteristics of the travel path.

**82-1487**

**Sound Propagation through Vegetation**

R. Bullen and F. Fricke

Dept. of Architectural Sci., Univ. of Sydney, Sydney, New South Wales 2006, Australia, J. Sound Vib., 80 (1), pp 11-23 (Jan 8, 1982) 8 figs, 2 tables, 9 refs

Key Words: Noise barriers, Trees (plants)

The propagation of sound through a large number of scatterers (i.e., trees) is treated in a similar way to a classical diffusion problem. A general differential equation governing the sound intensity is derived which is valid under certain conditions, notably that the depth of the belt of vegetation is large, and absorption small. The predictions of this theory are compared with results derived from a small scale model study, and with some field measurements. They are also compared with published field data.

**82-1488**

**The Transformation between the Mode Representation and the Generalized Ray Representation of a Sound Field**

T.-F. Gao and E.-C. Shang

Inst. of Acoustics, Academia Sinica, Peking, China, J. Sound Vib., 80 (1), pp 105-115 (Jan 8, 1982) 4 figs, 14 refs

Key Words: Sound waves, Wave propagation

The mode generation function and the generalized ray generation function are introduced for a stratified waveguide. It is proved that they are a Fourier transform pair when lateral waves do not appear. Mode representation and the generalized ray representation satisfy the Poisson summation formula. Furthermore, the local conversion relation between the mode and the ray is considered from the point of view of member selection.

**82-1489**

**Spatial Stochastic Systems Theory and Its Application to Fields and Waves in Random Moving Media, II: Preliminary Application to Scattering and Reverberation**

K.C. Liu

Dept. of Physics and Electrical Engrg., Univ. of Bremen, 2800 Bremen 33, Fed. Rep. Germany, J. Sound Vib., 80 (4), pp 473-498 (Feb 22, 1982) 5 figs, 23 refs

Key Words: Acoustic scattering, Reverberation, Statistical analysis, Moving scatterers

A preliminary application is made of the general theory and method proposed in the preceding companion paper to the calculation of statistical properties of the reverberation and scattered field caused by randomly moving discrete scatterers. Two kinds of random motion of scatterers are considered: the displacements of the scatterers are stochastic vector processes with stationary increments, but they are mutually independent; the displacements of the scatterers are stationary stochastic vector processes, but they can be statistically dependent.

## 82-1490

## High Frequency Sound Emission from Moving Point Multipole Sources Embedded in Arbitrary Transversely Sheared Mean Flows

M.E. Goldstein
NASA Lewis Res. Ctr., Cleveland, OH 44135, J. Sound Vib., 80 (4), pp 499-522 (Feb 22, 1982) 6 figs, 25 refs

Key Words: Acoustic emission, Moving loads, Point source excitation

Formulas are derived for the high frequency sound emission from moving point multipole sources embedded in an arbitrary uni-directional transversely sheared mean flow. The results are used to study the sound generated by non-axisymmetric turbulent jets. The effect of the asymmetry in both the mean flow and the source distribution is accounted for by a circumferential directivity factor, which is easily calculated from the solution of a second order ordinary differential equation in the general case and from an explicit formula when the mean flow is symmetric but the source location is not. This factor is used to assess the potential of employing asymmetric velocity profiles that redirect the sound upward to reduce the noise radiation below the flight path of a jet aircraft.

## 82-1491

## An Adaptive Digital Filter for Broadband Active Sound Control

C.F. Ross
Dept. of Engrg., Univ. of Cambridge, Cambridge CB2 1PZ, UK, J. Sound Vib., 80 (3), pp 381-388 (Feb 8, 1982) 7 figs, 4 refs

Key Words: Active control, Noise reduction, Digital filters

The application of digital filtering to active sound control systems has increased their flexibility and reliability, thus enabling optimum devices to be produced. A further improvement is possible; the systems can be made adaptive so that optimum performance is maintained. An algorithm is presented for using the signal from a monitoring microphone to adjust the controller's characteristic. The optimum characteristic is obtained quickly due to the rapid convergence of the algorithm. The scheme has been used to control the sound transmitted in a wind tunnel which had a flow with a Mach number of 0·1. The adaptive scheme was able to cope with large variations in the flow velocity and consequent changes in the characteristic required to maintain optimum performance. The attenuation in sound level achieved in the duct came within 2 dB of the theoretical maximum (which is limited by coherence) over more than two octaves of broadband sound.

## 82-1492

## An Algorithm for Designing a Broadband Active Sound Control System

C.F. Ross
Dept. of Engrg., Univ. of Cambridge, Cambridge, UK, J. Sound Vib., 80 (3), pp 373-380 (Feb 8, 1982) 4 figs, 5 refs

Key Words: Active control, Noise reduction, Digital filters

The filtering techniques used in active sound control systems have been analogue but these are rapidly becoming obsolete because of their lack of stability and versatility. The microprocessor gives digital techniques an edge both on grounds of convenience and economics; moreover the performance of digital filtering is far superior to that of analogue methods. An algorithm is presented which can be used to assess the optimum filter characteristics required for active sound control systems with a single degree of freedom. In the process the system is subjected to three random noise tests which directly yield the characteristics of the filter. The algorithm has been tried out in practical applications and shown to be both quick and convenient to use.

## 82-1493

## Hovercraft Environmental Noise: a Review and Future Prospects

J.W. Leach
Dept. of Industry, UK, Aeronaut. J., 86 (851), pp 29-39 (Jan 1982) 8 figs, 48 refs

Key Words: Amphibious vehicles, Ground effect machines, Noise generation

The paper reviews the development of amphibious hovercraft and considers the noise emission levels of current types of in-service craft. A brief reference is also made to side wall hovercraft and hover barges. An outline of suggested methods for quantitative measurement of noise level and format is given, should legislation be deemed necessary at some future date. Recommendations are made for further research and development programs aimed at achieving significant improvement in the next generation of hovercraft.

## SHOCK EXCITATION

(Also see Nos. 1357, 1486)

### 82-1494

### The Effectiveness of Trenches in Reducing Seismic Motion

T.W. May and B.A. Bolt
Engrg. Geoscience, Univ. of California, Berkeley, CA 94720, Earthquake Engrg. Struc. Dyn., 10 (2), pp 195-210 (Mar-Apr 1982) 15 figs, 4 tables, 19 refs

Key Words: Seismic barriers, Time domain method, Damping effects, Viscoelastic damping

The effect of placing barriers in the travel path of P, SV and SH seismic waves has been studied using time-domain solutions of plane-strain finite element programs for two-dimensional crustal models. The wavefields considered propagate parallel to the free surface of an elastic medium consisting of a single layer over a halfspace. Barriers take the form of open-air trenches. Effects of damping are assessed by considering representative viscoelastic conditions. Computations are presented as the ratio of spectral energy observed at a point with the barrier system in place in the model to the spectral energy observed at the same point without the barrier system in the model. These spectral ratios are dependent upon the direction of wave propagation. The calculations brought to light the marked role of surficial layering and attenuation properties of the surface rocks or soils on the effectiveness of seismic trench barriers. Barrier models without these features cannot in general reliably predict seismic wavefields at the surface.

### 82-1495

### Apparent Propagation Velocity of Body Waves

M.J. O'Rourke, M.C. Bloom, and R. Dobry
Rensselaer Polytechnic Inst., Troy, NY 12181, Earthquake Engrg. Struc. Dyn., 10 (2), pp 283-294 (Mar-Apr 1982) 9 figs, 4 tables, 24 refs

Key Words: Seismic waves, Wave propagation, Bridges, Pipelines, Underground structures, Buildings, Foundations, Multistory buildings, Earthquake damage

The apparent horizontal propagation velocity, i.e., the propagation velocity of seismic waves with respect to the ground surface, is discussed in this paper. This parameter is needed to determine the effects of earthquakes on long structures such as bridges and buried pipelines as well as the torsional rotation of foundations of multi-story buildings. A time window intensity tensor is used to determine the predominant directions of ground motion during an earthquake. Considering the reflection of waves at a free surface, an approximate relationship between the predominant direction and the angle of incidence of body waves with respect to the ground surface is presented. Knowing the material properties of the top layer and the angle of incidence, the desired propagation velocity with respect to the ground surface is readily calculated.

### 82-1496

### Considerations on the Residual Contribution in Modal Analysis

A.J. Salmonte
Empresarios Agrupados, Madrid, Spain, Earthquake Engrg. Struc. Dyn., 10 (2), pp 295-304 (Mar-Apr 1982) 4 figs, 5 tables, 8 refs

Key Words: Seismic analysis, Residual mode method, Response spectra

Mode superposition has become a standard tool in the treatment of seismic analysis. Its advantages are appealing to the analyst. After years of widespread use of the method, it could be said that it is well understood, both in theory and application. However, its routine application can lead to errors caused by the analyst neglecting truly representative modes in the system response. In this paper, a very simple technique is suggested for representing, under certain conditions, the effect of the higher modes: the residual mode method. The effectiveness of the method in the context of response spectrum analysis is discussed, and such analysis is illustrated by a numerical example.

### 82-1497

### Beyond Three Decades of Continuous Research at UTIAS on Shock Tubes and Waves

I.I. Glass
Inst. for Aerospace Studies, Toronto Univ., Downsview, Ontario, Canada, Rept. No. UTIAS-45, CN-

ISSN-0082-5247, 80 pp (July 1981)
N82-10060

Key Words: Shock waves, Shock tube testing

Analytical and experimental research on nonstationary shock waves, rarefaction waves and contact surfaces is reviewed. Some unique facilities were used to study the properties of planar, cylindrical, and spherical shock waves and their interactions. Investigations were also performed on shock-wave structure and boundary layers in ionizing argon, water-vapor condensation in rarefaction waves, magnetogasdynamic flows, and the regions of regular and various types of Mach reflections of oblique shock waves. Explosively driven implosions were employed as drivers for projectile launchers and shock tubes, and as a means of producing industrial-type diamonds from graphite, and fusion plasmas in deuterium. The effects of sonic-boom on humans, animals, and structures formed an important part of the investigations. Shock waves in dusty gases, the viscous and vibrational structure of weak spherical blast waves in air, and oblique shock wave reflections were emphasized.

## VIBRATION EXCITATION

(Also see No. 1559)

### 82-1498

### Nonlinear In-Plane and Out-of-Plane Vibrations in Solar Arrays

M.A. Zak
Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, AIAA J., 20 (3), pp 430-433 (Mar 1982)
6 figs, 9 refs

Key Words: Solar arrays, Vibration analysis

The results of analytical investigations of nonlinear effects in in-plane and out-of-plane vibrations of solar arrays caused by surface wrinkling of solar array blankets is presented. It is shown that nonlinearities generated by wrinkles are important even for small deformations. An approximate analytical solution describing the frequency dependencies of the amplitudes of in-plane vibrations is derived. A parametrical resonance of out-of-plane vibrations induced by in-plane vibrations is described.

### 82-1499

### Application of Harmonic Analysis Method to Aeroelastic Stability Analysis of Conventional and Supercritical Airfoils in Transonic Flow

A.G. Striz
Ph.D. Thesis, Purdue Univ., 296 pp (1981)
UM 8200740

Key Words: Airfoils, Harmonic analysis, Flutter

Flutter analyses are performed for two-dimensional airfoils plunging and pitching in small disturbance unsteady transonic flow. Two conventional airfoils and two supercritical airfoils are investigated. The aerodynamic data are obtained by using the steady and unsteady transonic aerodynamic codes STRANS2 and UTRANS2. These C.F.D. codes are based on the harmonic analysis method for moderate reduced frequencies and utilize a relaxation scheme to solve the steady and unsteady transonic small disturbance equations. Four unsteady aerodynamic coefficients are computed by plunging and pitching the airfoils about the quarter chord axis at various values of low reduced frequency. Standard U-g method is used for flutter analysis. The aeroelastic parameters considered are: position of the mass center, airfoil-air mass density ratio, plunge-to-pitch frequency ratio, and position of the elastic axis. For all four airfoils, the effect of Mach number on flutter speed and the corresponding reduced frequency is studied for several values of these parameters. The transonic dip phenomenon is illustrated and discussed.

### 82-1500

### Flutter and Time Response Analyses of Three Degree of Freedom Airfoils in Transonic Flow

C.-H. Chen
Ph.D. Thesis, Purdue Univ., 128 pp (1981)
UM 8200656

Key Words: Airfoils, Multidegree of freedom systems, Flutter

Flutter and time response analyses are performed for a NACA 64A006 conventional and a MBB A-3 supercritical airfoil, both oscillating with plunge, pitch, and aileron pitch degrees of freedom in transonic, small disturbance flow. The aerodynamic coefficients are calculated using the transonic code LTRAN2-NLR. The effects of various kinds of aeroelastic parameters on flutter speeds for the bending-torsion, bending-aileron, and torsion-aileron branches are studied. The flutter speeds associated with the bending-torsion branch are plotted against Mach number for different parameter values, and the transonic dip phenomenon is demonstrated. To study the flutter modes, the flutter speed, the amplitude ratio, and the phase difference are plotted against the mass ratio for both a two degrees of freedom and a three degrees of freedom case.

### 82-1501

### Application of Transonic Codes to Flutter Analysis of Conventional and Supercritical Airfoils

T.Y. Yang, P. Guruswamy, and A.G. Striz
Purdue Univ., W. Lafayette, IN, J. Aircraft, 19 (3), pp 211-220 (Mar 1982) 13 figs, 4 tables, 34 refs

Key Words: Airfoils, Flutter

Transonic flutter analyses are performed for two conventional airfoils and three supercritical airfoils. Two degrees of freedom, plunging and pitching about the quarter-chord axis, are considered. The aerodynamic data are obtained by using the two transonic aerodynamics codes LTRAN2 (indicial and time integration methods) and STRANS2/UTRANS2 (harmonic analysis method). The unsteady aerodynamic data are computed within the low reduced frequency range. For all airfoils, the effect of Mach number on flutter speed is studied for several values of four different aeroelastic parameters.

## 82-1502
## Design for Active Flutter Suppression and Gust Alleviation Using State-Space Aeroelastic Modeling

M. Karpel
Stanford Univ., Stanford, CA, J. Aircraft, 19 (3), pp 221-227 (Mar 1982) 6 figs, 22 refs

Key Words: Flutter, Control equipment, Wind-induced excitation

An analytical design technique for an active flutter-suppression and gust-alleviation control system is presented. It is based on a rational approximation of the unsteady aerodynamic loads in the entire Laplace domain, which yields matrix equations of motion with constant coefficients. Some existing rational approximation schemes are reviewed, and a new technique which yields a minimal number of augmented states for a desired accuracy is presented. The state-space aeroelastic model is used to design a constant gain, partial-feedback control system, which simultaneously assures stability and optimizes any desired combination of gust response parameters throughout the entire flight envelope.

## 82-1503
## Excitation of the Wall Region by Sound in Fully Developed Channel Flow

K.M.M. Alshamani, J.L. Livesey, and F.J. Edwards
Univ. of Tech., Baghdad, Iraq, AIAA J., 20 (3), pp 334-339 (Mar 1982) 9 figs, 20 refs

Key Words: Fluid-induced excitation, Periodic excitation, Random excitation

Artificial excitation of wall region flow is attempted using air as the working fluid. Sound is injected into the flow by means of a brass diaphragm mounted flush with the channel wall. When operating, the diaphragm is vibrated at its center, with its rim fixed. The effect of such excitation on the axial turbulence intensity near the wall is examined. Sinusoidal and random excitations are considered. Sinusoidal disturbances corresponding to the inner layer bursting frequency are found to have a negligible effect on the turbulence intensity. Random disturbances can lead to either an increase or a decrease in the turbulence intensity, depending on the particular type of disturbance. The amount of increase or decrease becomes more pronounced as the level of the disturbance increases or the Reynolds number decreases. Furthermore, the influence of the disturbance becomes stronger as the wall is approached.

## 82-1504
## Sub/Superharmonic Oscillations and the Perturbation Procedure

J. Padovan and I. Zeid
Dept. of Mech. Engrg., Univ. of Akron, Akron, OH 44325, Intl. J. Nonlin. Mech., 16 (5/6), pp 465-478 (1981) 12 figs, 12 refs

Key Words: Subharmonic oscillations, Superharmonic vibration, Harmonic response, Perturbation theory

The problem of sub/super and harmonic oscillations of nonlinear systems is considered. This is made possible by the development of a modified version of the constrained Linstedt-Poincare perturbation procedure. The generality of the procedure is such that the existence of sub/super and harmonic oscillations can be simultaneously handled. The methodology developed is such that no a priori knowledge of solution form is necessary to establish the existence of such oscillation modes. Based on the approach, the steady response of Duffing's equation wherein sub/super and harmonic oscillations exist is studied in detail.

## 82-1505
## Comparison of Stabilization Modes of a Symmetrical Third-Order Non-Linear Oscillatory Unit

B.Z. Kaplan
Dept. of Electrical Engrg., Ben-Gurion Univ. of the Negev, Beer-Sheva, Israel. Intl. J. Nonlin Mech., 16 (5/6), pp 417-425 (1981) 2 figs, 14 refs

Key Words: Oscillators, Polyphase operation

The possibility of constructing symmetrical stabilized oscillator models that operate in several phases instead of operating

in two phases, as is more usual, is considered. Symmetrical oscillator models operating in three phases are discussed comprehensively. An interesting feature of their dynamic behavior; e.g., the appearance of limit cycles which are regionally stable and not orbitally stable, as is the case in the two phase counterpart, is suggested and dealt with.

### 82-1506
### Analysis of Forced Vibration by Reduced Impedance Method (Part 2. Introduction of New Curve Fitting Technique)

A. Nagamatsu and Y. Kagohashi
Faculty of Engrg., Tokyo Inst. of Tech., Meguroku, Tokyo, Japan, Bull. JSME, 25 (199), pp 76-87 (Jan 1982) 9 figs, 4 tables, 5 refs

Key Words: Forced vibration, Impedance technique, Curve fitting

The analytical expression and representation of the dynamic characteristics of the frequency responses are discussed. All frequency responses are expressed as superposition of the dynamic responses of the systems with one degree of freedom. First, a method is introduced to represent the natural frequencies and the equivalent stiffness of the undamped responses calculated numerically by the reduced impedance method. Next, the usual method of curve fitting is improved to represent the natural frequencies, the equivalent stiffness and the equivalent damping ratios of the damped responses determined experimentally. The least square technique is adopted on the methods proposed in the present report in order to minimize the errors which appear in representation of the response curve with the dynamic characteristics. The present methods are applied to several model structures, and usefulness of these methods is proved as the result.

### 82-1507
### Random Waves in Solid Media

A.J. Beltzer
School of Aerospace, Mech. and Nuclear Engrg., Univ. of Oklahoma, 865 Asp Ave., Rm. 212, Norman, OK 73109, Shock Vib. Dig., 14 (3), pp 3-6 (Mar 1982) 2 figs, 15 refs

Key Words: Random response, Wave propagation, Acoustic emission, Composite materials, Seismic analysis, Reviews

This is the first survey of recent developments in a new topic of solid dynamics: propagation of random waves in regular (nonrandom) solid media. Basic problems are formulated and results obtained. Applications in the mechanics of composite materials, acoustic emission, and earthquake engineering are discussed.

### 82-1508
### Review of Vortex-Induced Asymmetric Loads - Part II

L.E. Ericsson and J.P. Reding
Lockheed Missiles and Space Co., Inc., 1111 Lockheed Way, Sunnyvale, CA 94086, Z. Flugwiss., 5 (6), pp 349-366 (1981) 28 figs, 94 refs

Key Words: Vortex-induced vibration, Reviews

The steady and unsteady vortex-induced loads on slender vehicles have been investigated. The study consisted of a review of pertinent two-dimensional and three-dimensional data, the development of analytic means for prediction of the upper limit for vortex-induced asymmetric loads, and the assessment of the importance of these loads to the vehicle dynamics of slender bodies of revolution. Boundary layer transition is found to have a dominant influence on static and dynamic vortex-induced loads. The predicted upper limit for vortex-induced asymmetric loads bounds all available experimental results from subcritical to high supercritical Reynolds numbers. The most powerful dynamic effect is that of the moving wall at the separation point, which has a wall-jet-like effect on the boundary layer transition and separation. The study showed that the poor capability of existing theory to predict the vortex-induced asymmetric loads is most likely due to the neglect of the dominating role played by a pointed, slender nose.

# MECHANICAL PROPERTIES

## DAMPING

### 82-1509
### Application of Hydrostatic Squeeze-Film Dampers

K.C. Choy and J.D. Halloran
Joy Manufacturing Co., Buffalo, NY 14227, ASLE Trans., 25 (2), pp 245-251 (Apr 1982) 14 figs, 13 refs

Key Words: Squeeze film dampers, Rotating machinery, Hydrostatic bearings

Squeeze-film dampers are often used to improve the stability of high-speed rotating machinery. The introduction of a hydrostatic bearing as an additional damper support can further optimize the loading capacity and damping effects of the support system. This paper investigates the application and limitations of a pressurized deep-pocket hydrostatic damper in a journal bearing-supported rotor system. A typical commercial centrifugal compressor is used as an example for the analysis. Both computer simulations and experimental results indicate that a support system using a journal bearing with offset halves and a hydrostatic damper can provide stable- and low-vibration operation. Data obtained from the same system with tilting-pad bearings are also presented for comparison.

**82-1510**

**Component Mode Analysis of a Simple Non-Linear, Non-Conservative System**

E.H. Dowell
Dept. of Mech. and Aerospace Engrg., Princeton Univ., Princeton, NJ 08544, J. Sound Vib., 80 (2), pp 233-246 (Jan 22, 1982) 7 figs, 36 refs

Key Words: Component mode analysis, Damping, Linear systems, Beams

A component mode analysis is carried out based upon the use of constraint conditions and Lagrange multipliers to treat exemplary physical systems with nonlinear damping. Both viscous and dry friction dampers attached to a linear elastic (beam) system are examined. The method is shown to possess conceptual and computational advantages by its ability to reduce the analysis of a multimode system to a small number of degrees of freedom equal to that associated with the nonlinear component.

**82-1511**

**Frequency-Dependent Damping in Structural Vibration Analysis by Use of Complex Series Expansion of Transfer Functions and Numerical Fourier Transformation**

R. Lundén and T. Dahlberg
Div. of Solid Mech., Chalmers Univ. of Tech., S-412 96, Gothenburg, Sweden, J. Sound Vib., 80 (2), pp 161-178 (Jan 22, 1982) 8 figs, 1 table, 20 refs

Key Words: Damping, Beams, Numerical analysis, Fourier transformation

The response of damped linear finite systems (discrete and continuous) to harmonic, stationary random, and transient excitations is studied. The assumed damping may be light or heavy, viscous and/or hysteretic (the latter being frequency-independent or frequency-dependent), and proportionally or non-proportionally distributed over the structure. Closed-form analytic transfer functions are derived for beam systems. In order to rationalize subsequent numerical calculations, the transfer functions are approximated by using truncated series. Complex eigenfrequencies of the structure and complex residues of the actual transfer function are used. Special interest is paid to the mathematical modeling of experimentally measured damping. Causality requirements are considered. Numerical examples are given. An efficient method (by which aliasing is eliminated) for numerical Fourier transformation has been developed and applied.

**82-1512**

**Quasi-Brittle Dynamic Fracture with Damping Due to Crack Edge Failure Zones**

L.M. Brock
Dept. of Engrg. Mech., Univ. of Kentucky, Lexington, KY 40506, Intl. J. Engrg. Sci., 20 (5), pp 663-672 (1982) 6 figs, 1 table, 8 refs

Key Words: Crack propagation, Damping

A model for dynamic crack propagation involving quasi-brittle fracture is studied in which adjacent material points in crack edge failure zones do not break completely apart instantaneously, but first undergo relative motion resisted by relative velocity-dependent stresses. An exact analysis for such a crack extending in an unbounded elastic plane under uniform shear and tension stresses indicates that the stress singularity orders are damped below the brittle fracture square-root value, and vanish at the Rayleigh wave speed. The power generated in the failure zones is also damped below the brittle fracture values, but the effect is not order-of-magnitude. Indeed, for small zone/crack size ratios, the approximate brittle fracture value can be spread out over the zone. In this case, however, the stresses are only weakly singular.

## FATIGUE

(Also see Nos. 1345, 1398, 1412, 1416, 1569)

**82-1513**

**Predicting Failure of Optical Glass Fibers**

J.E. Ritter, Jr. and K. Jakus
Dept. of Mech. Engrg., Univ. of Massachusetts, Am-

herst, MA, Tech. Rept. 1 Oct 80 - 1 Oct 81, 14 pp (Oct 1981)
AD-A107 245

Key Words: Fibers, Glass, Fatigue life

Factors that affect failure predictions of optical glass fibers in service were studied. These factors include the effect of various polymeric coatings on the fatigue behavior, dependency of long term fatigue predictions on the form of the subcritical crack velocity, and prediction of long-length strengths from strength data of short-length specimens.

## 82-1514
## On the Effect of Frequency on Fatigue Life

K.C. Valanis
College of Engrg., Univ. of Cincinnati, Cincinnati, OH, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 21-32, 13 refs

Key Words: Fatigue life, Strain rate, Frequencies

In this paper an endochronic fracture criterion is used to examine aspects of the strain rate effect on fatigue life. Specifically, the influence of frequency on the number of cycles to failure is derived analytically and the manner in which an initial stress hold time affects the subsequent fatigue life is discussed. The frequency effect is shown to obey the customary power law established in the literature on the basis of experimental observations.

## 82-1515
## Effect of Tangential Traction and Roughness on Crack Initiation/Propagation During Rolling Contact

N. Soda and T. Yamamoto
Univ. of Tokyo, Tokyo, Japan, ASLE Trans., 25 (2), pp 198-206 (Apr 1982) 15 figs, 3 tables, 17 refs

Key Words: Fatigue life, Rolling friction, Rolling contact bearings

Rolling-fatigue tests of 0.45 percent carbon steel rollers were carried out using a four-roller-type rolling-contact fatigue tester. Tangential traction and surface roughness of the harder mating rollers were varied and their effect was studied. The results of the study indicate that the fatigue life decreases when traction is applied in the same direction as that of rolling. When the direction of traction is reversed, the life increases over that obtained with zero traction. The roughness of harder mating rollers also has a marked influence on life. The smoother the mating roller, the longer the life. Microscopic observation of specimens revealed that the initiation of cracks during the early stages of life is more strongly influenced by the surface roughness, while the propagation of these cracks in the latter stages is affected mainly by the tangential traction.

## 82-1516
## A Micromechanical Theory of Fatigue Crack Initiation from Notches

K. Tanaka and T. Mura
Dept. of Civil Engrg. and Materials Res. Ctr., The Technological Inst., Northwestern Univ., Evanston, IL 60201, Mechanics of Materials, 1 (1), pp 63-73 (Jan 1982) 7 figs, 29 refs

Key Words: Fatigue life, Crack propagation

The fatigue crack initiation along the slip bands emanating from notches is analyzed theoretically with the use of the dislocation dipole accumulation model proposed previously by the authors. The complex function analysis for an elliptical notch under the anti-plane shear gives a quantitative method for assessment of the reduction of fatigue strength as a function of the notch tip radius, the notch size and the elastic stress concentration factor. Special cases of this theoretical analysis yield several semi-empirical formulae commonly used by engineers for data collection. In the derivation, the limitations for each engineering approach are clarified. The material properties are included in the present micromechanical theory as the slip band length and the dislocation frictional stress.

## 82-1517
## Fatigue Crack Growth Properties of Rail Steels

D. Broek and R.C. Rice
Battelle Columbus Labs., OH, Rept. No. FRA/ORD-81/30, DOT-TSC-FRA-80-29, 160 pp (Oct 1981) PB82-129594

Key Words: Fatigue life, Crack propagation, Railroad tracks, Steel

Fatigue crack propagation properties of rail steels were determined experimentally. The investigation covered 66 rail steels. The effects of the following parameters were studied: stress ratio (ratio of minimum to maximum stress in a cycle), frequency, temperature and orientation. The results were

presented on the basis of the stress intensity factor. The threshold value of the stress intensity was determined. An equation correlating the crack growth rate and the stress intensity factor was established. A limited number of mixed mode crack growth tests were conducted. Also the behavior of surface flaws was studied.

### 82-1518
### Fatigue Crack Growth in Ductile Metals

J. Weertman
Dept. of Materials Sci. and Engrg. and Materials Res. Ctr., Northwestern Univ., Evanston, IL, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 11-19, 2 figs, 2 tables, 18 refs

Key Words: Metals, Ductile materials, Fatigue life, Crack propagation

The theory of the growth of a fatigue crack that is based on the crack tip shear sliding model is reviewed and extended in this paper. This model is appropriate for describing the growth of fatigue cracks in intrinsically ductile material in which a crack tip can never advance in a cleavage mode.

### 82-1519
### Prediction of Fatigue Crack Growth in Rail Steels

D. Broek and R.C. Rice
Battelle Columbus Labs., OH, Rept. No. FRA/ORD-81/31, DOT-TSC-FRA-80-30, 147 pp (Oct 1981) PB82-129602

Key Words: Fatigue life, Crack propagation, Railroad tracks, Steel

Measures to prevent derailments due to fatigue failures of rails require adequate knowledge of the rate of propagation of fatigue cracks under service loading. The report presents a computational model for the prediction of crack growth in rails. The model was derived on the basis of experiments of crack growth under service simulation loading. The applications of the model are discussed. Material data on fatigue crack growth in rail steels are required for the execution of the predictive model.

### 82-1520
### Fatigue Crack Growth and Overload Retardation in 2048 Aluminum

J.M. Baik, L. Hermann, and R.J. Asaro
Div. of Engrg., Brown Univ., Providence, RI, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov. 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 33-51, 17 figs, 2 tables, 18 refs

Key Words: Aluminum, Fatigue life, Crack propagation

This paper is concerned with a study of the macro- and micro-mechanics of fatigue crack growth in an age-hardenable 2048 aluminum alloy. Special attention was given to the importance of microstructure, including grain size and aging treatment in crack growth, on the phenomena of crack tip closure, and on overload retardation effects. Crack closure was studied in detail throughout the course of this research program and its use in describing crack growth was explored. Discussion is also included on the experimental techniques used in this research since they are novel and should have quite general applicability in fracture mechanics testing. The results show that crack closure levels, crack growth rates and overload retardation are all influenced by microstructure.

### 82-1521
### Crack Tip Deformation and Fatigue Crack Growth

H.-W. Liu
Dept. of Chemical Engrg. and Materials Sci., Syracuse Univ., Syracuse, NY, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov. 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 53-79, 25 figs, 1 table, 27 refs

Key Words: Fatigue life, Crack propagation

Fatigue crack growth is caused by crack tip cyclic plastic deformation. Both the macro-analysis and the moire strain measurements indicate that crack tip cyclic deformation is a function of $\Delta K$, R-ratio, and plate thickness, t. Therefore, da/dN must be dependent on these three parameters. The cyclic crack tip unzipping shear decohesion process is described, and the unzipping fatigue crack growth process is modeled by the finite element method. The calculated crack growth rate agrees well with the experimental measurements. The unzipping model is used to study the growth of microcracks and the fatigue crack growth in a ferritic-martensitic two phase steel. A model of fatigue crack growth threshold is proposed. The proposed model agrees with the observed crack growth behavior in the near threshold region. A quantitative analysis of fatigue limit and microstructure is made. The analysis provides a quantitative approach to optimize the microstructure for high fatigue strength.

**82-1522**

**A CTOD-Based Mechanics Approach to the Short-Crack Problem in Fatigue**

M.F. Kanninen, J. Ahmad, and B.N. Leis
Battelle, Columbus Labs., Columbus, OH, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 81-90, 3 figs, 17 refs

Key Words: Fatigue life, Crack propagation

A new approach to the problem associated with the anti-conservative nature of fatigue crack growth rate predictions for cracks that are physically small is presented. This approach focuses on the crack tip crack opening displacement (CTOD) as a characterizing parameter. Heuristic calculations are made which demonstrate an accelerated crack growth rate for small cracks. The results strongly suggest the possible utility of a CTOD-based approach for the resolution of this and other problems where the assumptions of linear elastic fracture mechanics are invalid.

**82-1523**

**Micromechanics of Fatigue Crack Initiation: Theory and Experimental Observations**

T.H. Lin
Mechanics and Structures Dept., Univ. of California, Los Angeles, CA, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 91-109, 11 figs, 42 refs

Key Words: Fatigue life, Crack propagation

Structures and machine parts generally are subject to repeated loadings, hence cracks frequently are caused by fatigue. Crack propagation predominates fatigue life in high stress while crack initiation may predominate in low stress loadings. Previous theories of fatigue crack initiation are reviewed. Present theory shows that one thin slice of metal slides during forward loading and another closely located slice slides during the reversed loading. Stress caused by slip clearly gives the monotonic build-up of the large local plastic strain in the two slices causing the start of an intrusion and the initiation of a crack. Electron-micrographs conclusively show the forward and backward slip in the two slices in a fatigue band. Stress fields caused by these two slid slices balance each other leaving little residual stress exterior to the fatigue band. This is verified by X-ray reflection patterns. This type of slip is also shown in a micrograph of the displacement of grain boundaries.

**82-1524**

**Dislocation Dipole Models for Fatigue Crack Initiation**

T. Mura and K. Tanaka
Dept. of Civil Engrg., Northwestern Univ., Evanston, IL, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 111-131, 12 figs, 25 refs

Key Words: Fatigue life, Crack propagation

Dislocation dipole models are proposed to explain consistently the following phenomena and empirical equations observed in cyclic loadings of materials: damage accumulation, ratcheting of plastic deformation in forward and backward directions, extrusions and intrusions, dislocation dipole structure of persistent slip bands, coffin-Manson's law, Petch's equation, crack initiation along grain boundaries, the fatigue strength reductions due to inclusions and notches, Neuber's and Peterson's formulae, and anomalous behavior of small cracks. The damage accumulation of cyclic loadings is assumed to be accumulation of dislocations. The fatigue crack initiates when the self energy of dislocations accumulated during n cycles of loading become a critical value.

**82-1525**

**Mechanics of Fatigue Crack Growth: Comparison between Fatigue and Ideal Cracks**

H. Kobayashi, H. Nakamura, and H. Nakazawa
Dept. of Physical Engrg., Tokyo Inst. of Tech., Tokyo, Japan, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov. 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 133-150, 18 figs, 1 table, 58 refs

Key Words: Fatigue life, Crack propagation

Significance of crack growth mechanisms and crack closure in fatigue crack growth is briefly discussed. Importance of crack closure in crack growth by a dominating striation mechanism is emphasized. Comparing the striation spacings, the opening stress intensity of a fatigue crack can be directly predicted for various materials.

**82-1526**

**Unifying Treatment of Fatigue Crack Growth Laws in Small, Large and Non-propagating Cracks**

H. Nisitani

Faculty of Engrg., Kyushu Univ., Fukuoka, Japan, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 151-166, 12 figs, 1 table, 17 refs

Key Words: Fatigue life, Crack propagation

Two representative fatigue crack growth laws $da/dN \propto \Delta K^m$ and $da/dN \propto \sigma^n a$, which hold in large and in small cracks respectively, formally contradict each other, unless $m = n = 2$. Usually, m is about 4 and n is much larger than 2. However, the two growth laws can be explained consistently from the same physical background, based on the assumption that the crack growth rate is proportional to the reversible plastic zone size. The existence of a non-propagating macro- or micro-crack is also understandable by the same assumption.

**82-1527**

**Mechanical and Non-Mechanical Categories in Fatigue Study: A Point of View for Small Surface Crack Problems**

H. Kitagawa, C.-M. Suh, Y. Nakasone, and S. Takahashi

Inst. of Industrial Sci., Univ. of Tokyo, Tokyo, Japan, "Mechanics of Fatigue," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 47, T. Mura, ed., pp 167-184, 19 figs, 3 tables, 11 refs

Key Words: Fatigue life, Crack propagation

Fatigue phenomena are composed of parts which are easily mechanically analyzed or determined and parts which are difficult to analyze. Based on this concept of separation, mechanical and non-mechanical, small surface crack problems are reexamined with recent data. Fatigue (and/or corrosion fatigue) process of smooth surface specimens is affected by many non-mechanical and mechanical factors. Most of this is caused by the initiation, growth and coalescence of multiple small surface cracks. The behavior of these cracks seems to be controlled by some mechanical factors. What phenomena should remain as non-mechanical is discussed.

## ELASTICITY AND PLASTICITY

**82-1528**

**Dynamic Crack Curving - A Photoelastic Evaluation**

M. Ramulu and A.S. Kobayaski

Dept. of Mech. Engrg., Univ. of Washington, Seattle, WA, Rept. No. TR-41, 32 pp (Oct 1981) AD-A107 238

Key Words: Crack propagation, Photoelastic analysis

The objective of the present study is to derive a dynamic crack curving criterion applicable to both mode I and combined modes I and II crack tip deformation. To this goal, dynamic extension of two static crack curving criteria, that is the maximum circumferential stress criterion and the minimum strain energy density criterion at a critical distance rc, was considered. The developed theoretical relations were evaluated numerically and crack velocity on crack curving direction were deduced. Crack curving angles predicted by the two dynamic crack curving criteria were then compared with experimental results obtained from past dynamic photoelastic investigation.

**82-1529**

**A Method for Obtaining Stress Intensity Factor by F.E.M. and Its Application to Dynamic Problem**

H. Wada, Y. Takagi, and T. Nishimura

Daido Inst. of Tech., Minami-ku, Nagoya, Japan, Bull. JSME, 25 (199), pp 1-8 (Jan 1982) 15 figs, 8 tables, 15 refs

Key Words: Fracture properties, Stress intensity factors, Finite element technique

A new method for obtaining the stress intensity factor is proposed. The constant strain element is used to approximate the integrated value of the stress with singularity in the neighborhood of the crack tip. Many numerical examples are investigated by the present method, and the results are compared with those obtained by other previous methods. It is shown that usual division of elements which are similar to those used in ordinary two-dimensional stress concentration problems can yield sufficiently accurate values of the stress intensity factors. Further, the applicability of the present method to dynamic problems with or without crack propagation is carefully examined.

# EXPERIMENTATION

## MEASUREMENT AND ANALYSIS

**82-1530**

**Method for the Objective Description of an Acoustic Environment Based on Short $L_{eq}$ Values**

P. Luquet
Dept. of Environmental Acoustics, Laboratoire National d'Essais, Paris, France, Appl. Acoust., 15 (2), pp 147-156 (Mar 1982) 4 figs, 3 tables, 4 refs

Key Words: Noise measurement, Measurement techniques

A new approach to environmental noise measurement and assessment is proposed; the method is based on the exploitation of the digitally recorded evolution of short term $L_{eq}$, which enables the a posteriori performance, very quickly and therefore at low cost, of any investigation, checking of interpretation, or automatic output of tables and graphs. It is designed to provide a numerical and graphical image containing enough information to be applicable to the objective assessment of any type of environmental noise.

## 82-1531
## Coefficient of Dynamic Friction via Analog Computer Data Reduction

A. Batenburg, H.O. Lagally, and R.J. Simko
Westinghouse Advanced Reactors Div., Madison, PA 15663, ASLE Trans., 25 (1), pp 49-54 (Jan 1982) 9 figs, 2 tables

Key Words: Coefficient of friction, Measurement techniques, Computer-aided techniques

A technique is described to determine the effective coefficient of dynamic friction from experimental data. The experiment consists of a rod that is being inserted in a test vessel which is subjected to a sinusoidal vibration input. The rod is impacted by three bushings. The actual impact forces are measured with three strain bolts per bushing. These nine impact forces, as well as rod position, are recorded continuously on an FM magnetic tape for playback and analysis. The data reduction is performed on an analog computer. All pertinent forces affecting vertical rod motion; i.e., gravity, fluid drag, buoyancy, and friction, as well as rod position and velocity, are included in this simulation. The end result of the analysis is the value of the effective coefficient of dynamic friction during a sinusoidal excitation. The analysis is straightforward and based on first principles. Results to date show excellent repeatability and accuracy.

## 82-1532
## The Influence of the Transmission Function of the Impedance Head on the Measurement of the Complex Elastic Modulus of a Viscoelastic Beam by the Driving Point Impedance Method

W. Ziolkowski and A. Sliwinski
Inst. of Physics, Univ. of Gdansk, 80-952 Gdansk, ul. Wita Stwosza 57, Poland, J. Sound Vib., 80 (2), pp 209-222 (Jan 22, 1982) 8 figs, 7 tables, 7 refs

Key Words: Testing techniques, Impedance technique, Test equipment and instrumentation, Modulus of elasticity, Beams, Viscoelastic properties

The driving point impedance method, as described theoretically by Snowdon for measuring the complex modulus of elasticity of a beam has been implemented experimentally, with use of a vibrational impedance head. The influence of the transmission function of the impedance head as well as of the mass impedance of the element connecting the beam and the head on the measured results for the complex moduli of elasticity of viscoelastic beams has been examined theoretically and experimentally. Values of the loss factor and Young's modulus have been determined at resonance and antiresonance modes of a Plexiglass beam over the frequency range 40 - 7000 Hz.

## 82-1533
## Mechanical Impedance Gauge Based on Measurement of Strains on a Vibrating Rod

L. Lagerkvist and B. Lundberg
Dept. of Mech. Engrg., Univ. of Lulea, S-951 87 Lulea, Sweden, J. Sound Vib., 80 (3), pp 389-399 (Feb 8, 1982) 4 figs, 1 table, 7 refs

Key Words: Mechanical impedance, Measuring instruments

An impedance gauge based on measurement of strains at two different cross-sections of a vibrating rod is analyzed and tested. The gauge rod, which may have variable characteristic impedance, is in contact with the object at one end and is driven by a harmonic vibrator at the other end. For conical and cylindrical rods explicit relations between point impedance and measured strains are derived. For a cylindrical gauge rod of steel with length 800 mm, diameter 10 mm, and distance between strain gauges 250 mm a fair agreement was generally obtained between experimental and theoretical point impedances of cylindrical test objects in the frequency range 50 Hz to 1·7 kHz. Significant improvements in accuracy over that of the tested prototype are expected to be feasible.

## 82-1534
## Modal Analysis Using a Fourier Analyzer, Curve-Fitting, and Modal Tuning

R.R. Craig, Jr. and Y.T. Chung

Ctr. for Aeronautical Res., Univ. of Texas at Arlington, TX, Rept. No. NASA-CR-161886, CAR-81-1, 41 pp (Oct 1, 1981)
N82-11490

Key Words: Modal analysis, Fourier analysis, Fast Fourier transform, Curve fitting, Tuning

The proposed modal test program differs from single-input methods in that preliminary data may be acquired using multiple inputs, and modal tuning procedures may be employed to define closely spaced frequency modes more accurately or to make use of frequency response functions (FRF's) which are based on several input locations. In some respects the proposed modal test program resembles earlier sine-sweep and sine-dwell testing in that broadband FRF's are acquired using several input locations, and tuning is employed to refine the modal parameter estimates. The major tasks performed in the proposed modal test program are outlined. Data acquisition and FFT processing, curve fitting, and modal tuning phases are described and examples are given to illustrate and evaluate them.

**82-1535**

**Determination of Aluminized Solid Propellant Admittances by the Impedance Tube Method**

J.D. Baum, B.R. Daniel, and B.T. Zinn
Georgia Inst. of Tech., Atlanta, GA, AIAA J., 20 (3), pp 417-421 (Mar 1982) 13 figs, 20 refs

Key Words: Mechanical admittance, Measurement techniques, Impedance technique

The adaptation of the impedance tube technique in the measurement of the admittances and response functions of aluminized solid propellants is described. These quantities are needed for combustion stability analysis of aluminized solid rocket motors. To determine the acoustic energy gains and losses in the impedance tube, the acoustic pressures (amplitude and phase) are measured in the tube during the quasi-steady burn period of a test through a distance covering two standing wave pressure minima. The measured data are then input into a data reduction computer program that is based upon the solution of the impedance tube wave equations and is capable of the simultaneous determination of the propellant admittance and the acoustic energy losses in the gas phase. Results obtained in a series of tests are presented. The paper demonstrates that the data measured in tests conducted with aluminized propellants and, hence, the determined propellant properties are more accurate than data measured in tests with nonaluminized propellants. Excellent agreement is demonstrated between the predicted and measured impedance tube wave structures. Finally, the results obtained by this method are utilized to determine the true role of aluminized solid propellants in the damping of combustion instabilities inside the rocket motor.

**82-1536**

**Instrumentation Development for Low Range, Long Line Differential Pressure Measurements**

W.L. Zabriski, S.C. Rogers, G.N. Miller, and K.G. Turnage
Instrumentation and Controls Div., Oak Ridge National Lab., ISA Trans., 20 (4), pp 61-75 (1981) 13 figs, 1 table, 19 refs

Key Words: Measuring instruments, Fluid-induced excitation, Nuclear reactors

A major experimental facility planned for the investigation of the reflood and refill phases of a loss-of-coolant accident in a pressurized water reactor (PWR) is a full-scale model of a PWR upper plenum. One of the goals of the test program is to determine the characteristics of the dynamic steam-water flow at the core/upper plenum interface. To meet this need, an instrumentation system designed to measure small differential pressures generated by this two-phase flow has been developed, fabricated, and evaluated.

**82-1537**

**Frequency Domain Design and State-Space Realization of 2-D Digital Filters**

J.H. Lodge
Ph.D. Thesis, Queen's Univ. at Kingston, Canada, 1981

Key Words: Frequency domain method, Digital filters

This thesis is concerned with the frequency domain design and the state-space realization of two-dimensional linear time-invariant digital filters. An iterative optimization technique, based on a modified Marquardt algorithm, is proposed for the design of asymmetric 2-D half-plane recursive digital filters with a zero phase implementation. An iterative optimization technique, based on the method of parallel tangents coupled with an efficient line searching technique, is proposed for the design of 2-D linear phase FIR digital filters. A technique is proposed for performing the bilinear transformation on 2-D state-space systems. The technique can be applied to a realization of a 2-D continuous system, with the transfer function denominator being a 2-D Hurwitzian polynomial, if its bilinear transformation possesses a discrete transfer function that satisfies Shanks' stability criterion.

**82-1538**

**Analysis of Dynamic Stresses and Motion of Pressure Gages in Alluvium**

C.C. Hudson and J.E. Schoutens

Kaman-Tempo, ISA Trans., 20 (4), pp 13-25 (1981) 7 figs, 3 tables, 14 refs

Key Words: Pressure gages, Explosion effects, Cratering

An analysis is presented of the dynamic stresses and motion of pressure cell bodies subjected to a high-stress, high-displacement ground environment. A number of pressure cell bodies mounted to steel plates were installed against the back of the driver wall of a large shock tube. The short cylindrical section of the cells faced the concrete wall on the other side of which 2570 kg of high explosives were detonated. The long cylindrical section on the other side of the steel plate pointed away from the wall into the alluvium, which covered the entire shock tube. After the passage of the shock wave, the pressure cells and their mounting plates were driven into the alluvium during the explosive cratering process. The recovered cell bodies were found tc have suffered an average axial strain of about 20 percent. An analysis of the process leading to the final cell shape was undertaken to understand the histories of the dynamic stresses and motion during cratering. The analysis combined analytical methods using known stress pulse shapes, assumptions about the behavior of steel at very high strain rates, and was aided by the use of Sandia's CHART D computer code.

## DYNAMIC TESTS

(Also see Nos. 1578, 1579, 1580, 1581, 1582)

### 82-1539

### Rubber-Metal Parts Testing Simulates Service Conditions

R.L. Clinard

Lord Corp., Indus. Res. and Dev., pp 130-133 (Mar 1982)

Key Words: Test facilities, Dynamic tests, Elastomeric bearings

A high energy dynamic test facility is described for testing bonded rubber-metal components. It comprises computer-controlled machines, which simulate the various forces and conditions a part will encounter in actual use. Computers create a "test profile" for each part, monitor the testing procedure, and collect performance data from the tests.

## SCALING AND MODELING

(Also see No. 1376)

### 82-1540

### TVC Noise Envelope - An Approach to Tip Vortex Cavitation Noise Scaling

R. Latorre

Dept. of Naval Architecture and Marine Engrg., Univ. of Michigan, Ann Arbor, MI, J. Ship Res., 26 (1), pp 65-75 (Mar 1982) 24 figs, 3 tables, 15 refs

Key Words: Ship noise, Propeller noise, Cavitation noise, Scaling

Noise measurements of the tip vortex cavitation generated by a large model hydrofoil and its one-quarter scale model are presented to discuss the features of tip vortex cavitation (TVC) noise and noise scaling. The concept of the TVC noise envelope is introduced to divide the cavitation noise into incipient and fully developed TVC noise. The cavitation noise scaling method of Bojorheden and Astrom is compared with the method of Levkovskii for scaling the fully developed TVC noise. A theoretical model of the cavitation nuclei spiraling around an idealized Rankine vortex is introduced to model the characteristic bursts in the incipient TVC noise and predict the inception of TVC noise. The simulation results for the large and small foils are shown to be in good agreement with the experimental noise measurements.

## DIAGNOSTICS

### 82-1541

### Dynamic Moire Methods for Detection of Loosened Space Shuttle Tiles

W.L. Snow, A.W. Burner, and W.K. Goad

NASA Langley Res. Ctr., Hampton, VA, Rept. No. NASA-TM-83205, 17 pp (Sept 1981)

N82-11434

Key Words: Failure detection, Periodic excitation, Moire effects, Heat shields, Tiles, Space shuttles

Moire fringe methods for detecting loose space shuttle tiles were investigated with a test panel consisting of a loose tile surrounded by four securely bonded tiles. The test panel was excited from 20 to 150 Hz with in-plane sinusoidal acceleration of 2 g (peak). If the shuttle orbiter can be subjected to periodic excitation of 1 to 2 g (peak) and rigid-body periodic displacements do not mask the change in the Moire pattern due to tile looseness, then the use of projected Moire fringes to detect out-of-plane rocking appears to be the most viable indicator of tile looseness since no modifications to the tiles are required.

## MONITORING

### 82-1542

### Vibration Signature Analysis and Acoustic-Emission Monitoring at Brayton Point. Final Report

P.J. Pekrul and S. Pennise
Rockwell International, Canoga Park, CA, Rept. No. EPRI-CS-1938, 268 pp (July 1981)
DE81904232

Key Words: Monitoring techniques, Acoustic emission, Vibration signatures

This report discusses the on-line monitoring techniques of vibration signature analysis and acoustic emission detection in light of a two-year monitoring program. Included in the study are discussions relating to sensor selection and location, spectrum analysis techniques, computation equipment, and display devices. Specific plant equipment failures occurred during the monitoring period, and the appropriate vibration and acoustic emission data are analyzed to assess any deviations prior to failure. Vibration signature analysis is seen to be a well-developed technique which can be successfully implemented into a preventative maintenance system for fossil plants.

# ANALYSIS AND DESIGN

## ANALYTICAL METHODS

(Also see No. 1572)

### 82-1543
### On the Effect of the Higher Modes on the Scattering of Love Waves at the Boundary of Welded Layered Quarter-Spaces

A. Niazy and M.H. Kazi
Dept. of Earth Sciences, Univ. of Petroleum and Minerals, Dhahran, Saudi Arabia, Bull. Seismol. Soc. Amer., 72 (1), pp 29-53 (Feb 1982) 11 figs, 4 refs

Key Words: Wave diffraction

An investigation is made as to the effect of higher modes on the scattering of plane, harmonic Love waves, normally incident (from either side) upon the plane of discontinuity in the horizontally discontinuous structure consisting of welded layered quarter-spaces with a plane surface. It is found that the effect of the higher modes on the scattering of an incident fundamental mode from hard into the soft medium is considerable for large impedance contrasts with or without body-wave conversion, and is negligible when the impedance contrast is low. Results indicate that contributions from body-wave conversion are important in higher Love mode studies when there is large contrast in the elastic constants of the media on the two sides of the vertical plane of discontinuity.

### 82-1544
### Use of Harmonic Basis Functions in Acoustic Finite Elements

J.J. Allen
Ph.D. Thesis, Purdue Univ., 160 pp (1981)
UM 8200638

Key Words: Finite element technique, Harmonic functions, Ducts, Sound propagation

An acoustic finite element is developed which employs harmonic of trigonometric basis functions in the element interpolation function. The harmonic element is conformable due to the use of an amplitude coordinate system for the harmonic terms. The calculation of the finite element matrices employ Filon numerical integration methods which make the use of harmonic terms competitive with polynomials. The harmonic element uses subparametric curvilinear mapping to approximate domain boundaries. The harmonic finite element is formulated for two dimensional axisymmetric duct acoustics. The element is applied to plane wave and higher mode inputs in a variable cross-sectional area duct. The finite element is used in the solution of dynamic equilibrium and eigenvalue acoustic matrices.

### 82-1545
### Finite Element Techniques for Static Stress and Free Vibration Analysis of Sandwich Composites

R.A. Brockman
Dayton Univ. Res. Inst., Dayton, OH, Rept. No. UDR-TR-80-134, AFWAL-TR-81-3007, 63 pp (Mar 1981)
AD-A107 095

Key Words: Sandwich structures, Composite structures, Free vibration, Finite element technique, Computer programs

Finite element solution techniques for stress and vibration analysis of layered sandwich panels are presented. The modeling approach considers each layer of the sandwich explicitly and can treat panels involving discrete stiffeners of two types. Static analyses of general sandwich panels can include mechanical and/or thermally-induced forces. Free vibration analysis is also considered. The associated computer program is suitable for operation at an interactive terminal, and includes provisions for automatic mesh genera-

tion and tabular output. Generated input and output data are in a form which may be accessed by existing computer graphics programs for plotting geometry and results. Sample analyses are presented to demonstrate the developed techniques.

**82-1546**

**Vibration of Prestressed Periodic Lattice Structures**

M.S. Anderson

NASA Langley Res. Ctr., Hampton, VA, AIAA J., 20 (4), pp 551-555 (Apr 1982) 8 figs, 8 refs

Key Words: Grids (beam grids), Stiffness methods, Matrix methods, Shells, Beams, Rings, Cable stiffened structures

Equations are developed for vibration of general lattice structures that have repetitive geometry. The method of solution is an extension of a previous paper on the buckling of similar structures. The theory is based on representing each member of the structure with the exact dynamic stiffness matrix and taking advantage of the repetitive geometry to obtain an eigenvalue problem involving the degrees-of-freedom at a single node in the lattice. Results are given for shell- and beam-like lattice structures and for rings stiffened with tension cables and a central mast. The variation of frequency with external loading and the effect of local member vibration on overall modes is shown.

**82-1547**

**A Method for Analyzing Parametrically Excited System by Matrix Function**

K. Okumura and A. Kishima

Mem. Fac. Engrg., Kyoto Univ., 43 (3), pp 376-386 (July 1981) 1 fig, 2 tables, 5 refs

Key Words: Parametric excitation, Matrix functions

A method for analyzing a parametrically excited system of higher order is described. The method is based on the theory of matrix function and the discrete Fourier transform. A numerical example is given.

**82-1548**

**Second Order Non-Linear Equations of Motion for Spinning Highly Flexible Line Elements**

M. Salama, M. Trubert, M. Essawi, and S. Utku

Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91103, J. Sound Vib., 80 (4), pp 461-472 (Feb 22, 1982) 1 fig, 6 refs

Key Words: Rotating structures, Spacecraft, Geometric imperfection effects, Equations of motion, Nonlinear theories

The second order nonlinear equations of motion are formulated for spinning line elements having little or no intrinsic structural stiffness. The derivation is based on the extended Hamilton's principle and includes the effect of initial geometric imperfections (axial, curvature, and twist) on the line element dynamics. For comparison with previous work, the nonlinear equations are reduced to a linearized form frequently found in the literature. The comparison revealed several new spin-stiffening terms that have not been previously identified and/or retained. They combine geometric imperfections, rotary inertia, Coriolis, and gyroscopic terms.

**82-1549**

**A Direct Variational Method for Non-Conservative System Stability**

J.G. Papastavridis

School of Engrg. Sci. and Mechanics, Georgia Inst. of Tech., Atlanta, GA 30332, J. Sound Vib., 80 (4), pp 447-459 (Feb 22, 1982)

Key Words: Variational methods, Flutter

Hamilton's principle is applied to analyze the problem of the stability of equilibrium of a discrete, holonomic, and scleronomic mechanical system under conservative and nonconservative (position and/or velocity dependent) forces. At the stability limit, the vanishing of the second order terms (in the deviations from equilibrium) of the total action change functional leads to the condition that the matrix of a certain quadratic form be singular; this yields the eigenvalue (frequency-load) curve. The flutter loads follow by setting the frequency derivative of the determinant of this matrix equal to zero; the energetic interpretation of this latter is also given. When the non-conservative forces go to zero it is shown that one recovers the well-known discrete conservative system stability criterion.

**82-1550**

**Sturm-Sequence Check for Eigenproblems Resulting from Variational Principles with Subsidiary Conditions**

H.A. Mang and H. Walter

Z. Angew. Math. Mech., 61 (11), pp 547-557 (1981) 4 figs, 2 tables, 4 refs

**Key Words:** Eigenvalue problems

Permitting determination of the number of eigenvalues smaller than a shift to the right of the largest one of these eigenvalues, the well-known Sturm-sequence check is an indispensable remedy for the numerical solution of large-scale eigenproblems. The purpose of the present paper is to adapt the classical Sturm-sequence check for application to eigenproblems derived from variational principles with subsidiary conditions in the form of linear constraint conditions for the unknowns, as are frequently occurring in technical applications. The scope of this article encompasses theoretical considerations as well as a numerical study. The objectives of the numerical investigation are twofold: numerical verification of the theoretical findings by means of transparent hand-calculation and application of a computer algorithm containing the modified Sturm-sequence check.

**82-1551**

## A Method of Successive Approximations for Structure Interaction Problems

I.S. Sandler
Weidlinger Associates, New York, NY, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 67-82, 16 figs, 11 refs

**Key Words:** Interaction: structure-medium, Infinite domain, Successive approximation method

A general method of successive approximations for nonlinear structure-medium interaction problems is reviewed. Some examples in which special versions of the method have been previously used are briefly discussed. These examples show that the method is equally valid when the medium is either a fluid or a solid. The method is particularly useful when the driving input occurs external to the structure and extends over distances much larger than the structural dimensions.

**82-1552**

## Solution of Complex Electromagnetic Penetration and Scattering Problems in Unbounded Regions

A. Taflove and K.R. Umashankar
Electronics Div., IIT Res. Inst., Chicago, IL, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov. 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 83-113, 17 figs, 1 table, 32 refs

**Key Words:** Interaction: structure-medium, Infinite domain, Finite difference technique, Time domain method, Electromagnetic properties

The finite-difference time-domain method for Maxwell's curl equations is applied to calculate the penetration and backscattering of electromagnetic waves for the sinusoidal steady state case. This method permits the treatment of arbitrary-shaped, extremely complex metal and dielectric structures located within a rectangular volume spanning up to 100 wavelengths for two-dimensional problems, or 5 wavelengths for three-dimensional problems, with a uniform spatial resolution of 0.05 wavelength within the volume. Electromagnetic field equivalence principles can be employed to simplify the treatment of field penetration into cavities through apertures, or the calculation of the far-field scattering pattern and radar cross section.

**82-1553**

## Numerical Methods for Unbounded Field Problems and a New Infinite Element Formulation

O.C. Zienkiewicz, P. Bettess, T.C. Chiam, and C. Emson
Dept. of Civil Engrg., Univ. College Swansea, UK, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov. 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 115-148, 7 figs, 8 tables, 40 refs

**Key Words:** Interaction: structure-medium, Infinite domain, Infinite element technique

The many methods available for unbounded continuum problems will be briefly reviewed. Two recent developments will then be discussed in more detail. The first is the improved damper of Bayliss, Gunzberger and Turkel which is shown to give a considerable increase in accuracy at minimal computational cost. The second is the mapped infinite element devised by Zienkiewicz, which is significantly simpler in concept than previous infinite elements, and can easily be coded.

**82-1554**

## Consistent Boundaries for Semi-Infinite Problems

J.L. Tassoulas, E. Kausel, and M. Roesset

Univ. of Texas at Austin, TX, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 149-166, 2 figs, 32 refs

Key Words: Interaction: structure-medium, Infinite domain, Boundary condition effects, Wave propagation, Soils

The formulation of a consistent boundary matrix to simulate the effect of a semi-infinite medium surrounding a core region discretized with finite elements is presented. Other solutions to this problem are briefly reviewed first, in order to put the method into proper perspective. The consistent boundary is derived in detail for the simple two dimensional case using both a discrete and a continuous displacement expansion in the horizontal direction. The extension of the formulation to a three dimensional problem in cylindrical coordinates is then discussed. Further applications of this basic formulation to problems involving propagation of waves through soil deposits, as well as the determination of foundation stiffnesses, or hydrodynamic forces due to fluid structure interaction are finally discussed.

**82-1555**

**An Evaluation of the Paraxial Boundary**

M. Cohen

California Inst. of Tech., CA, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 167-182, 10 figs, 15 refs

Key Words: Interaction: structure-medium, Infinite domain, Boundary condition effects

A recently proposed silent boundary technique, the extended-paraxial boundary, is summarized and discussed. This method was devised to absorb infinitely radiating waves in a finite, computational grid. The basic ideas of the paraxial approach are presented, along with some comparisons to a second silent boundary method, the viscous boundary. In this comparison, while analytical results indicate that while the extended-paraxial boundary enjoys a distinct advantage over the viscous boundary in cancelling wave reflections, numerical tests revealed only a small superiority.

**82-1556**

**A Non-Reflecting Boundary for Explicit Calculations**

R.R. Kunar and J. Marti

Principia Mechanica Ltd., London, UK, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 183-204, 10 figs, 12 refs

Key Words: Interaction: structure-medium, Infinite domain, Finite element technique, Boundary condition effects, Time domain method

The dynamic analysis of infinite domains using finite models can be improved through the use of non-reflecting boundaries. These boundaries have been developed and successfully implemented in frequency domain analysis. This paper proposes a method that is applicable to explicit time domain calculations. Two sets of boundary zones with different boundary conditions are used. The boundary conditions are selected such that all reflections are cancelled when the solutions in the two sets of boundary zones are superimposed. Continuous superposition of the two solutions eliminates reflections as they arise. This avoids the problem of multiple reflections, which otherwise results in an exponential increase of the number of solutions to be superimposed. The governing equations are solved only once in the interior of the model and twice (once for each set of boundary conditions) in a narrow band of elements along the boundary. The theoretical justification of the method is presented, together with some examples which show the procedure and its implementation to be both accurate and efficient.

**82-1557**

**Geometrically Corrected Viscous Boundaries for Steady State Acoustic Scattering and Radiation Problems**

A.J. Kalinowski

Naval Underwater Systems Ctr., New London, CT, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 205-224, 16 figs, 14 refs

Key Words: Interaction: structure-medium, Interaction: structure-fluid, Submerged structures, Finite element technique, NASTRAN (computer programs)

A procedure is presented for numerically treating scattering or radiation problems encountered in linear elastic fluid-structure interaction problems. In the past, viscous absorbing boundaries have been used at the fluid mesh termination boundary when numerically solving fluid-structure interaction problems subject to steady state harmonic inputs. A geometric correction to the viscous boundary approach is presented. The implementation of the correction depends on

the geometric shape of the submerged structure and upon the orientation of the fluid medium boundary cut surfaces on which the viscous absorbers are placed. Formulations for the boundary condition are given for both pressure variable representation and displacement variable representation for the fluid medium. Comparisons between classical and numerically obtained solutions are presented, wherein the NASTRAN general purpose finite element computer program is used to implement the viscous boundary formulation.

### 82-1558
### Elastic Wave Scattering by Embedded Structures -- A Survey of the T-Matrix Approach

V.V. Varadan and V.K. Varadan
Wave Propagation Group, Dept. of Engrg. Mech., The Ohio State Univ., Columbus, OH, "Computational Methods for Infinite Domain Media-Structure Interaction," Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, AMD-Vol. 46, A.J. Kalinowski, ed., pp 1-36, 18 figs, 33 refs

Key Words: Interaction: structure-medium, Elastic waves, Wave diffraction

A complete survey of the T-matrix or null field approach to elastic wave scattering is made beginning with a discussion of the field equations, integral representations and the free space Green's dyadic for an elastic continuum. The basic T-matrix formulation for a cavity, rigid or elastic inclusion embedded in an elastic solid is presented. A discussion of the various possible choices of basis functions for representation of the surface and interior fields is given. The more complicated problem involving a solid-fluid interface is discussed and expressions for the T-matrix of a fluid inclusion in an elastic solid as well as a solid inclusion in a nonviscous fluid are derived. The symmetry and unitarity properties of the scattering matrices which are a consequence of reciprocity and conservation of energy are then discussed. Extension of the T-matrix approach to more complicated scatterers like layered scatterers, two or more finite scatterers as well as scatterers embedded in half-space is also discussed. The steps involved in numerical computations are discussed in the last section and sample results for the various cases that have been discussed are then presented.

### 82-1559
### Computational Methods of Robust Controller Design for Aerodynamic Flutter Suppression

L.R. Anderson
Dept. of Aerospace and Ocean Engrg., Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, Rept. No. NASA-CR-164983, VPI-AERO-125, 86 pp (Nov 15, 1981) (Pres. at the 3rd Intl. Conf. on Math., California, July 29-31, 1981)
N82-12080

Key Words: Control equipment, Flutter

The development of Riccati iteration, a tool for the design and analysis of linear control systems is examined. It is applied to the problem of pole placement and order reduction in two-time scale control systems. Order reduction, yielding a good approximation to the original system, is demonstrated using a 16th order linear model of a turbofan engine. A numerical method for solving the Riccati equation is presented and demonstrated for a set of eighth order random examples. A literature review of robust controller design methods follows which includes a number of methods for reducing the trajectory and performance index sensitivity in linear regulators. Robust controller design for large parameter variations is discussed.

## MODELING TECHNIQUES

### 82-1560
### A Mathematical Model for Treating Ring Vortex-Shedding from Orifices

R.E. Schwirian
Westinghouse Electric Corp., West Mifflin, PA, "Flow Induced Vibration of Power Plant Components," The Pressure Vessels and Piping Conference. ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980. ASME PVP-41. M.K. Au-Yang, ed., pp 139-157, 5 figs, 11 refs

Key Words: Mathematical models, Piping systems, Openings, Fluid-induced excitation, Vortex-induced vibration, Acoustic resonance

A model is presented for the analysis of ring vortex-shedding from orifices. The governing equations of the model, which are based on the fluid mechanical momentum equation and on the phenomenology of vortex-shedding, contain empirical parameters which must be determined experimentally. Using the available experimental data, calculations of mode frequencies are performed for several pipe/orifice acoustical systems. The agreement between theory and experimental results is good, but more experimental data are needed before the model can be considered a practical tool for the analysis of orifice-induced mechanical and acoustical resonances.

**82-1561**

**Regularity of Traffic Noise Signals**

P.K. Andersen

Statistical Res. Unit, Danish Medical and Social Sci. Res. Councils, Universitetsparken 5, DK-2100 Copenhagen Ø, Denmark, J. Sound Vib., 80 (2), pp 267-274 (Jan 22, 1982) 1 fig, 25 refs

Key Words: Traffic noise, Mathematical models

The flexibility of the filtered renewal process compared with the filtered Poisson process as a model for traffic noise is demonstrated. This is done by proving that for the family of gamma distributed headways with coefficient of variation less than one the variance of the traffic noise signal never exceeds that of the corresponding filtered Poisson process. It is proved that the inverse inequality holds for the family of completely monotone distributions, which includes all finite mixtures of exponential distributions. The theory is illustrated by some numerical calculations.

## NUMERICAL METHODS

**82-1562**

**Development of a Numerical Method for the Calculation of Power Absorption by Arrays of Similar Arbitrarily Shaped Bodies in a Seaway**

J.H. Duncan and C.E. Brown

Hydronautics, Inc., Laurel, MD, J. Ship Res., 26 (1), pp 38-44 (Mar 1982) 4 figs, 18 refs

Key Words: Numerical analysis, Water waves, Energy absorption, Buoys, Power plants (facilities)

A computational procedure is developed using first-order hydrodynamic theory to predict the motions and power absorption from arrays of similar three-dimensional buoys. The buoy shape and the number and placement of the buoys may be arbitrarily selected. The program provides for waves of selected frequency and direction or combinations thereof by simple superposition; thus, the effects on energy absorption of wave energy spectral distributions or short-crestedness can be analyzed. The computer model has been validated by comparison of its results with published analytically derived power optimal solutions for five buoys in a linear array. The program provides the power output of each buoy in the array with the associated motions in six degrees of freedom. The limited number of cases studied has provided the interesting result that identical buoys in an array tend to absorb wave energy at rates close to those of optimized systems for which buoy amplitude and phasing would have to be controlled.

## PARAMETER IDENTIFICATION

**82-1563**

**Nonparametric Identification of a Class of Nonlinear Close-Coupled Dynamic Systems**

F.E. Udwadia and C.P. Kuo

Jet Propulsion Lab., Pasadena, CA, Rept. No. NASA-CR-164948, JPL-PUB-81-48, 76 pp (Oct 1, 1981) N82-11098

Key Words: Nonparametric identification technique, Spacecraft

A nonparametric identification technique for the identification of close coupled dynamic systems with arbitrary memoryless nonlinearities is presented. The method utilizes noisy recorded data (acceleration, velocity and displacement) to identify the restoring forces in the system. The masses in the system are assumed to be known (or fairly well estimated from the design drawings). The restoring forces are expanded in a series of orthogonal polynomials and the coefficients of these polynomial expansions are obtained by using least square fit method. A particularly simple and computationally efficient method is proposed for dealing with separable restoring forces. The identified results are found to be relatively insensitive to measurement noise. An analysis of the effects of measurement noise on the quality of the estimates is given.

**82-1564**

**Parameter Estimation of Large Flexible Aerospace Structures with Application to the Control of the Maypole Deployable Reflector**

M.J. Balas

Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NASA-CR-164971, 20 pp (Nov 6, 1981) N82-11099

Key Words: Parameter identification technique, Spacecraft

Systems such as the Maypole deployable reflector have a distributed parameter nature. The flexible column and hoop structure and the circular antenna of 30-100 meter diameter which it supports are described by partial, rather than ordinary, differential equations. Progress completed in reduced order modeling and controller design and digital parameter estimation and control is summarized. Topics covered include deployment and on-orbit operation; quasi-static (steady state) operation; dynamic distributed parameter system; autoregressive moving average identification; frequency domain procedures; direct or implicit active control; adaptive observers; parameter estimation using a linear

reinforcement learning factor; feedback control; and reduced order modeling for nonlinear systems.

**82-1565**

**Design of Experiments for Eigenvalue Identification in Distributed-Parameter Systems**

E. Rafajlowicz
Control Systems Group, Inst. of Engrg. Cybernetics, Tech. Univ. of Wroclaw, Wroclaw, Poland, Intl. J. Control, 34 (6), pp 1079-1094 (Dec 1981) 15 refs

Key Words: System identification techniques, Eigenvalue problems, Continuous parameter method

The problem of optimal design of experiments for identification of distributed systems described by a linear, parabolic partial differential equation is considered. Conditions of an experiment, which consists of the spectral density of a stochastic input signal and a probability measure corresponding to positions of sensors, are chosen to maximize the accuracy of a finite number of the system's eigenvalue estimates. Conditions for optimality of the experiment design are derived.

## DESIGN TECHNIQUES

(See No. 1571)

## COMPUTER PROGRAMS

**82-1566**

**The Dynamic Design-Analysis Method (DDAM) in NASTRAN**

M.M. Hurwitz
David W. Taylor Naval Ship Res. and Dev. Ctr., Bethesda, MD, Rept. No. DTNSRDC-81/073, 26 pp (Oct 1981)
AD-A107 074

Key Words: DDAM (computer programs), Computer programs, NASTRAN (computer program), Shock resistant design, Shipboard equipment response, Finite element technique

This report describes the theory, implementation, and use of the Dynamic Design-Analysis Method (DDAM) in the NASTRAN finite element structural analysis computer program. DDAM is the procedure used in the shock design of shipboard equipment. Since such equipment is also frequently analyzed with NASTRAN, the inclusion of DDAM in NASTRAN greatly enhances the efficiency of the design-analysis process.

**82-1567**

**TLUSH: A Computer Program for the Three-Dimensional Dynamic Analysis of Earth Dams**

T. Kagawa, L.H. Mejia, H.B. Seed, and J. Lysmer
Earthquake Engrg. Res. Ctr., Univ. of California, Berkeley, CA, Rept. No. UCB/EERC-81/14, NSF/CEE-81044, 118 pp (Sept 1981)
PB82-139940

Key Words: Computer programs, Dams, Earth structures, Dynamic structural analysis, Earthquake response

Two-dimensional finite element techniques which use the complex response method and therefore permit variations in modulus and damping in different elements of a soil structure have been extended to three dimensions, with a constraint on the possible deformations of the finite element model. The present version of the computer program TLUSH constitutes a further development of these procedures and includes the following: complete freedom for the selection of the direction of the earthquake motions, complete freedom in the deformational modes of the model, a new interpolation scheme, a nodal point and element data generation routine, more efficient element stiffness generation routines and a more efficient program structure that has lower memory requirements. The program TLUSH can take into account the strong nonlinear effects characteristic of soil masses subjected to strong earthquake motions.

**82-1568**

**On Elasto-Plastic Response of Structural Systems Subjected to Dynamic Loadings**

R.Y.-P. Mak
Ph.D. Thesis, Univ. of California, Los Angeles, CA, 171 pp (1981)
UM 8201129

Key Words: Computer programs, Elastic plastic properties

The primary objective of this dissertation is to investigate the problem of numerical instability due to unexpected unloading in an elasto-plastic structural system. An iterative solution scheme has been developed and implemented into the computer code NONSAP (nonlinear structural analysis program). The resulting algorithm is exercised on several

example problems and gives satisfactory results. Closely related to the problem of unloading is the effectiveness of the convergence criteria. Existing convergence criteria are evaluated and a new criterion, termed the stress criterion, is developed. This new criterion is found to be superior over existing criteria and carries a physical interpretation by relating convergence to the confidence level of the material properties.

# GENERAL TOPICS

## CONFERENCE PROCEEDINGS

**82-1569**
**Mechanics of Fatigue**
Winter Annual Meeting of the ASME, Washington, DC, Nov 15-20, 1981, ASME-AMD-Vol. 47, T. Mura, ed., ASME 1981, 196 pp, $30.00, Bk. No. H00197

Key Words: Fatigue life, Proceedings

Emphasis in this symposium was focused on the more theoretical aspects of fatigue. The speakers discussed principles of mechanics as they relate to fatigue phenomena and also addressed basic questions of fatigue crack initiation and growth. The symposium showed the community of theoretical and applied mechanics that there is a need for basic theories of fatigue, and that mechanics plays an important role in these theories. Individual papers published in this volume are abstracted in the appropriate sections of this issue.

**82-1570**
**Flow-Induced Vibration of Power Plant Components**
The Pressure Vessels and Piping Conference, ASME Century 2 -- Emerging Technology Conferences, San Francisco, CA, Aug 12-15, 1980, ASME-PVP-41, M.K. Au-Yang, ed., ASME 1980, 190 pp, $24.00, Bk. No. H00168

Key Words: Fluid-induced excitation, Power plants (facilities), Proceedings

This volume contains papers presented in the "vibration" half of the Symposium on Vibration and Transient Response of Power Plant Components held during the 1980 Bicentennial Pressure Vessel and Piping Conference. The Symposium, which is sponsored by the Operations, Applications, and Components Committee of the Pressure Vessel and Piping Division, covers a wide range of structural dynamics problems associated with the power generation industry during both normal operations and hypothetical accident conditions. Because of the more diversified nature of the "transient" half of the Symposium, papers on this topic have been published in separate pamphlets. Pertinent individual papers are abstracted in the appropriate section of this issue.

**82-1571**
**Flow-Induced Vibration Design Guidelines**
Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engineering, Solar Energy Divisions of ASME, Denver, CO, June 21-25, 1981, ASME-PVP-Vol. 52, P.Y. Chen, ed., ASME 1981, 143 pp, $30.00, Bk. No. H00188

Key Words: Fluid-induced excitation, Design techniques, Proceedings

The purpose of this monograph is to provide FIV design guidelines which consolidate state-of-the-art information so that the designer can identify the applicable method for his design considerations. Individual papers published in this monograph are abstracted in the appropriate sections of this issue.

**82-1572**
**Computational Methods for Infinite Domain Media-Structure Interaction**
Winter Annual Meeting of ASME, Washington, DC, Nov 15-20, 1981, ASME-AMD-Vol. 46, A.J. Kalinowski, ed., ASME 1981, 236 pp, $40.00, Bk. No. H00195

Key Words: Interaction: structure-medium, Infinite domain, Proceedings

This volume treats dynamic media-structure interaction problems, where an obstacle (structure) is embedded in an infinite or semi-infinite domain. The treatment of the infinite domain portion surrounding the obstacle is the central theme. Various techniques for treating this class problem are presented. Individual papers published in this volume are abstracted in the appropriate sections of this issue.

## CRITERIA, STANDARDS, AND SPECIFICATIONS

(Also see Nos. 1360, 1361)

**82-1573**

**Standards and Criteria for Noise Control – An Overview**

K. Eldred

Ken Eldred Engrg., P.O. Box 1037, Concord, MA 01742, Noise Control Engrg., 18 (1), pp 16-23 (Jan-Feb 1982) 6 tables, 32 refs

Key Words: Noise reduction, Standards and codes, Reviews, Human response

An overview of standards and criteria for noise control with emphasis on the effects of noise on people is presented. The activity in the voluntary standards system is described briefly and examples are given of the general standards available for noise control application and use. The area of federal regulation and information documents pertaining to environmental noise control in the community and the workplace are summarized. A summary of recommended criteria for noise control with respect to speech interference, risk of hearing loss, community reaction to noise, and requirements in specific spaces, is provided.

## BIBLIOGRAPHIES

**82-1574**

**Vibrational Analysis in Aerodynamics. 1972-1981 (Citations from the International Aerospace Abstracts Data Base)**

NTIS Rept. for Jan 1972 - Dec 1981, 137 pp (Dec 1981)

PB82-858531

Key Words: Bibliographies, Aerodynamic excitation, Vibration analysis, Flutter, Aerial rudders, Rotor blades (turbomachinery), Panels, Airfoils, Aircraft

This bibliography contains citations concerned with design and performance relative to aerodynamic vibration. Among the topics discussed are torsion blade flutter; vibration generated by rudders, rotor blades, panels, air foils; vortex shedding; load control; and helicopter gust response flutter. Aircraft vibrational analyses by means of analog computer simulation, auto-flight control systems, and structural dynamics of aircraft are included with consideration for flight vehicle vibration control and reduction.

**82-1575**

**Vibrational Analysis in Aerodynamics. 1970-1981 (Citations from the Engineering Index Data Base)**

NTIS Rept. for Jan 1970 - Dec 1981, 97 pp (Dec 1981)

PB82-858549

Key Words: Bibliographies, Aerodynamic excitation, Vibration analysis, Flutter, Ground effect machines, Blades, Helicopters, Aircraft wings, Spacecraft

Reports are cited which discuss aerodynamic aircraft and spacecraft generated vibration. Structural design flutter in air-cushion vehicles; helicopter blade flutter; steady lift wing flutter; bending-torsion flutter at supersonic, subsonic and transonic speeds; wake-induced wing flutter; stalled and unstalled flutter, and panel flutter are among the conditions discussed relative to such analysis techniques as finite element analysis. Ground vibration test results, space vehicle automated design, and calculation of critical flutter speeds for fixed-wing aircraft are included with respect to vibrational suppression performance.

**82-1576**

**Vibrational Analysis in Aerodynamics. 1970-1981 (Citations from the NTIS Data Base)**

NTIS Rept. for Jan 1970 - Dec 1981, 218 pp (Dec 1981)

PB82-858556

Key Words: Bibliographies, Aircraft, Flutter

This bibliography cites reports on excitation and analysis techniques for flight flutter tests. Although fixed-wing aircraft, space flight vehicles, VTOL and V/STOL vehicles are included, helicopter generated vibration analysis is emphasized in this bibliography. Among the variations of flutter included are unsteady airloads, fluidelastic vibration, rotor blade in forward flight, turbomachine blades, composite wings, response of reentry vehicles, tail vibration, hingeless helicopter rotors and hinge-type, propeller whirl and SST related vibration. Analysis by aeroelastic and dynamic finite element techniques and collocation methods by computer analysis are included relative to dynamic structural damping and computer graphics in aeronautical engineering to suppress aircraft and spacecraft vibration.

**82-1577**

**Computer Analysis of Fracture Properties. January, 1976 - December, 1981 (Citations from the Energy Data Base)**

NTIS Rept. for Jan 1976 - Dec 1981, 80 pp (Dec 1981)
PB82-858788

Key Words: Bibliographies, Fracture properties

This bibliography covers computer-aided, theoretical, experimental, and observational analyses of fracture properties of natural and man-made materials and structures. Computer calculations, computerized simulation, and mathematical modeling of fracture properties are considered.

**82-1578**
**Nondestructive Testing of Steels. January, 1970 - December, 1981 (Citations from the Engineering Index Data Base)**
NTIS Rept. for Jan 1970 - Dec 1981, 293 pp (Dec 1981)
PB82-858036

Key Words: Bibliographies, Nondestructive tests, Steel

This bibliography covers techniques and apparatus for the nondestructive testing or examination of various types of steel in a wide variety of forms (e.g., steel stocks, cast steels, fabricated steel products etc.) for the detection of flaws or defects which affect their properties and behavior. Some attention is given to the principles of nondestructive steel inspection.

**82-1579**
**Nondestructive Testing of Structural Welds. January, 1976 - December, 1981 (Citations from the Energy Data Base)**
NTIS Rept. for Jan 1976 - Dec 1981, 205 pp (Dec 1981)
PB82-858457

Key Words: Bibliographies, Nondestructive tests, Welded joints

This bibliography covers techniques and technology for the nondestructive testing or evaluation of weldments in objects and structures of various sizes, for the detection of flaws or defects which affect their properties and performance. Special attention is given to apparatus, structures, and equipment used in a wide variety of energy industry activities.

**82-1580**
**Nondestructive Testing of Structural Welds. January, 1970 - December, 1981 (Citations from the NTIS Data Base)**
NTIS Rept. for Jan 1970 - Dec 1981, 218 pp (Dec 1981)
PB82-858440

Key Words: Bibliographies, Nondestructive tests, Welded joints

This bibliography covers theory, techniques, and technology for the nondestructive testing or examination of weldments in objects and structures of various sizes, for the detection of flaws or defects which affect their properties and performance. Special attention is given to the detection of fatigue in welds.

**82-1581**
**Nondestructive Testing of Structural Welds. January, 1972 - December, 1981 (Citations from the International Aerospace Abstracts Data Base)**
NTIS Rept. for Jan 1972 - Dec 1981, 222 pp (Dec 1981)
PB82-858465

Key Words: Bibliographies, Nondestructive tests, Welded joints

Citations cover techniques and technology for the nondestructive testing or evaluation of weldments in objects and structures of various shapes and sizes for the detection of flaws or defects which affect their properties or performance. Considerable attention is paid to aerosapce apparatus, equipment, and structures.

**82-1582**
**Nondestructive Testing of Joints. January, 1972 - December, 1981 (Citations from the International Aerospace Abstracts Data Base)**
NTIS Rept. for Jan 1972 - Dec 1981, 126 pp (Dec 1981)
PB82-858762

Key Words: Bibliographies, Nondestructive tests, Joints (junctions)

Citations in this bibliography cover techniques and technology for the nondestructive testing or evaluation of joints (bonded, brazed, glued, soldered, etc.) for the detection of flaws or defects which may affect their properties and behavior. Attention is also given to evaluations of the strength of various types of joints.

# AUTHOR INDEX


Adams, R.D. . . . . 1432
Ahmad, J. . . . . 1522
Åkesson, B. . . . . 1408
Allen, J.J. . . . . 1544
Alshamani, K.M.M. . . . . 1503
Amier, R.K. . . . . 1387
Andersen, P.K. . . . . 1561
Anderson, L.R. . . . . 1559
Anderson, M.S. . . . . 1546
Aristizabal-Ochoa, J.D. . . . . 1477, 1479
Armstrong, E.L. . . . . 1416
Asaba, E. . . . . 1419
Asaro, R.J. . . . . 1520
August, R. . . . . 1417
Bache, T.C. . . . . 1486
Baghdadi, S. . . . . 1348
Baik, J.M. . . . . 1520
Balas, M.J. . . . . 1564
Banda, S.S. . . . . 1389
Banon, H. . . . . 1481
Barker, T.G. . . . . 1486
Barlow, J.B. . . . . 1394
Barney, G.B. . . . . 1477
Batenburg, A. . . . . 1531
Baum, J.D. . . . . 1535
Baxter, S.M. . . . . 1476
Beltzer, A.J. . . . . 1507
Benda, B.J. . . . . 1373
Bernitsas, M.M. . . . . 1429
Berthier, Y. . . . . 1415
Bettess, P. . . . . 1553
Blachut, J. . . . . 1436
Blevins, R.D. . . . . 1465
Bloom, M.C. . . . . 1495
Bohm, G.J. . . . . 1377
Bohm, L.H. . . . . 1466
Bolleter, U. . . . . 1465
Bolt, B.A. . . . . 1494
Borcherts, R.H. . . . . 1352
Brambilla, L. . . . . 1381
Brock, L.M. . . . . 1512
Brockman, R.A. . . . . 1545
Broek, D. . . . . 1517, 1519
Brown, C.E. . . . . 1562
Brown, M.G. . . . . 1486
Bullen, R. . . . . 1487
Burner, A.W. . . . . 1541
Cabannes, H. . . . . 1427
Campany, D. . . . . 1351
Caveny, L.H. . . . . 1402
Caves, J.L. . . . . 1473
Celep, Z. . . . . 1446
Chadha, J.A. . . . . 1423
Chang, C.-J. . . . . 1369
Chen, C.-H. . . . . 1500
Chen, S. . . . . 1438
Chen, Y.N. . . . . 1469
Cheung, Y.K. . . . . 1482
Chiam, T.C. . . . . 1553
Chonan, S. . . . . 1445
Chopra, A.K. . . . . 1370, 1371
Choy, K.C. . . . . 1509
Christiano, P. . . . . 1457
Chung, Y.T. . . . . 1534
Clinard, R.L. . . . . 1539
Clough, R.W. . . . . 1372
Cohen, M. . . . . 1555
Coleby, J.R. . . . . 1456
Connors, H.J. . . . . 1439, 1467
Corley, W.G. . . . . 1477, 1479
Cotter, S.L. . . . . 1354
Craig, R.R., Jr. . . . . 1534
Crispell, C. . . . . 1420
Dahlberg, T. . . . . 1511
Daniel, B.R. . . . . 1535
Daniel, J.I. . . . . 1479
del Cid, L. . . . . 1383
Dobry, R. . . . . 1495
Dobrzynski, W.M. . . . . 1396
Dowell, E.H. . . . . 1510
Duffey, T.A. . . . . 1460
Duncan, J.H. . . . . 1562
Edwards, F.J. . . . . 1503
Egle, D.M. . . . . 1485
Eldred, K. . . . . 1573
Emson, C. . . . . 1553
Ericsson, L.E. . . . . 1508
Ertepinar, A. . . . . 1440
Essawi, M. . . . . 1548
Etsion, I. . . . . 1424
Evans, J.W. . . . . 1417
Every, M.J. . . . . 1380
Eyre, R. . . . . 1407
Fancher, P.S. . . . . 1386
Fiorato, A.E. . . . . 1477, 1479
Flack, R.D. . . . . 1339
Fox, D.W. . . . . 1451
Frater, J.L. . . . . 1417
Fricke, F. . . . . 1487
Fukuda, M. . . . . 1343
Fung, Y.T. . . . . 1441
Gao, T.-F. . . . . 1488
Garg, V.K. . . . . 1385
Gazetas, G. . . . . 1367
Gergely, P. . . . . 1442
Gilbert, D.A.M. . . . . 1483
Glass, I.I. . . . . 1497
Glegg, S.A.L. . . . . 1399
Goad, W.K. . . . . 1541
Goldstein, M.E. . . . . 1490
Gorman, D.J. . . . . 1463, 1470
Greene, W.H. . . . . 1391
Greve, F. . . . . 1400
Griffin, O.M. . . . . 1379, 1380
Gupta, A.P. . . . . 1452
Gupta, D.C. . . . . 1447
Gupta, R.B. . . . . 1357
Gürkök, A. . . . . 1440
Guruswamy, P. . . . . 1501
Hall, J.F. . . . . 1370, 1371
Halloran, J.D. . . . . 1509
Hansen, C.H. . . . . 1411
Haraux, A. . . . . 1427
Harris, A.S. . . . . 1360
Haruyama, Y. . . . . 1410
Hasegawa, H. . . . . 1453
Hashimoto, F. . . . . 1433
Hashimoto, T. . . . . 1472
Hermann, L. . . . . 1520
Hill, E.v.K. . . . . 1485
Hjorth-Hansen, E. . . . . 1474
Hobson, D.E. . . . . 1423
Hollingworth, G.H. . . . . 1483
Hongo, K. . . . . 1419

Hopkins, H.G. . . . . 1352
Howe, M.S. . . . . 1401
Howell, L.J. . . . . 1384
Hsieh, J.S. . . . . 1422
Hsu, T.-K. . . . . 1336
Hudson, C.C. . . . . 1538
Hui, W.H. . . . . 1395
Hurwitz, M.M. . . . . 1566
Ida, M. . . . . 1341
Iguchi, M. . . . . 1461, 1462
Ikeda, T. . . . . 1340
Imaichi, K. . . . . 1347
Ishida, Y. . . . . 1340
Iwatsubo, T. . . . . 1337
Jain, M. . . . . 1452
Jakus, K. . . . . 1513
Johnson, J.J. . . . . 1373
Jones, R.T. . . . . 1407
Kagawa, T. . . . . 1567
Kagohashi, Y. . . . . 1506
Kalinowski, A.J. . . . . 1557
Kamel, A. . . . . 1374
Kanninen, M.F. . . . . 1522
Kanou, T. . . . . 1390
Kaplan, B.Z. . . . . 1505
Kapp, J.A. . . . . 1437
Karpel, M. . . . . 1502
Karpp, R.R. . . . . 1460
Karshenas, S. . . . . 1363
Kasuba, R. . . . . 1417
Kato, O. . . . . 1412
Katz, R. . . . . 1383
Kausel, E. . . . . 1554
Kawai, R. . . . . 1337
Kazamaki, T. . . . . 1410
Kazao, Y. . . . . 1342
Kazi, M.H. . . . . 1543
Keast, D.S. . . . . 1360
Keer, L.M. . . . . 1368
Kellenberger, W. . . . . 1344
Kikuchi, K. . . . . 1341
King, R. . . . . 1380
Kishima, A. . . . . 1547
Kishimoto, R. . . . . 1428
Kitagawa, H. . . . . 1527
Kitazawa, I. . . . . 1428
Ko, P.L. . . . . 1471
Kobatake, K. . . . . 1472
Kobayakawa, M. . . . . 1390, 1393
Kobayashi, H. . . . . 1525
Kobayaski, A.S. . . . . 1528
Koishikawa, A . . . . . 1472
Kojima, E. . . . . 1353
Kojima, N. . . . . 1343
Koss, L.L. . . . . 1358
Krause, W. . . . . 1346
Kruger, W.D. . . . . 1346
Ku, C.-C. . . . . 1484
Kume, Y. . . . . 1433
Kunar, R.R. . . . . 1556
Kunz, D.L. . . . . 1388
Kuo, C.P. . . . . 1563
Kurihara, K. . . . . 1382
Lagally, H.O. . . . . 1531
Lagerkvist, L. . . . . 1533
Lakin, W.D. . . . . 1431
Lanes, R.F. . . . . 1339
Latorre, R. . . . . 1540
Lau, S.L. . . . . 1482
Leach, J.W. . . . . 1493
Lees, A.W. . . . . 1435
Leis, B.N. . . . . 1522
Lin, T.H. . . . . 1523
Lin, Y.K. . . . . 1364
Lipowczan, A. . . . . 1403
Liu, H.-W. . . . . 1521
Liu, K.C. . . . . 1489
Livesey, J.L. . . . . 1503
Lodge, J.H. . . . . 1537
Luco, J.E. . . . . 1362
Lueke, J.E. . . . . 1348
Lukose, K. . . . . 1442
Lundberg, B. . . . . 1533
Lundén, R. . . . . 1511
Luquët, P. . . . . 1530
Lysmer, J. . . . . 1567
MacAdam, C.C. . . . . 1386
Maekawa, S. . . . . 1397
Mak, R.Y.-P. . . . . 1568
Malanoski, S.B. . . . . 1338
Mang, H.A. . . . . 1550
Marshall, A. . . . . 1423
Marshall, R.D. . . . . 1361
Marti, J. . . . . 1556
Matsushita, O. . . . . 1341
May, T.W. . . . . 1494
Mazumdar, J. . . . . 1456
McClintock, F.A. . . . . 1345
Meade, K.P. . . . . 1368
Mejia, L.H. . . . . 1567
Mestre, V. . . . . 1400
Metcalfe, R. . . . . 1425
Meyers, B.L. . . . . 1450
Micci, M.M. . . . . 1402
Miller, G.N. . . . . 1536
Miller, N.P. . . . . 1360
Moe, G. . . . . 1474
Moffatt, J.A. . . . . 1358
Mori, H. . . . . 1410
Morisawa, M. . . . . 1382
Morris, R.L. . . . . 1352
Mukhopadhyay, M. . . . . 1448
Mulcahy, T.M. . . . . 1376
Mura, T. . . . . 1516, 1524
Murata, M. . . . . 1343
Muro, H. . . . . 1412
Nachman, A. . . . . 1431
Nagakura, H. . . . . 1353
Nagamatsu, A. . . . . 1506
Nagaraj, V.T. . . . . 1409
Nair, S. . . . . 1385
Nakamura, H. . . . . 1525
Nakasone, Y. . . . . 1527
Nakazawa, H. . . . . 1525
Narayanan, S. . . . . 1444
Neal, T.R. . . . . 1460
Nefske, D.J. . . . . 1384
Neidhardt, R. . . . . 1418
Neise, W. . . . . 1349
Nelson, P.A. . . . . 1406
Nezu, K. . . . . 1449
Niazy, A. . . . . 1543
Nielson, C.E. . . . . 1351
Nishimura, T. . . . . 1529
Nisitani, H. . . . . 1526
Niwa, A. . . . . 1372
Niyogi, A.K. . . . . 1450
Nowinski, J.L. . . . . 1443
Ohashi, H. . . . . 1350
Ohmae, H. . . . . 1382
Ohmi, M. . . . . 1461, 1462
Okami, Y. . . . . 1382
Okaue, M. . . . . 1337
Okubo, H. . . . . 1390
Okumura, K. . . . . 1547
Oppenheim, B.W. . . . . 1426
Orahata, I. . . . . 1461
O'Rourke, M.J. . . . . 1495
Overvik, T. . . . . 1474
Padovan, J. . . . . 1504
Paidoussis, M.P. . . . . 1464
Papastavridis, J.G. . . . . 1549
Pekrul, P.J. . . . . 1542

Pennise, S. . . . . 1542
Persoon, A.J. . . . . 1359
Pettigrew, M.J. . . . . 1463, 1471
Pines, S. . . . . 1392
Platzer, M.F. . . . . 1395
Play, D. . . . . 1415
Pope, L.D. . . . . 1411
Pretlove, A.J. . . . . 1407
Prohl, M.A. . . . . 1413
Prucz, J. . . . . 1458
Pyatt, K.D. . . . . 1486
Quam, D.L. . . . . 1389
Rafajłowicz, E. . . . . 1565
Ramulu, M. . . . . 1528
Reding, J.P. . . . . 1508
Rice, R.C. . . . . 1517, 1519
Ritchie, R.O. . . . . 1345
Ritter, J.E., Jr. . . . . 1513
Roesset, M. . . . . 1554
Rogers, S.C. . . . . 1536
Rocklausen, L. . . . . 1555
Ross, C.F. . . . . 1491, 1492
Rowe, C.N. . . . . 1416
Saatcioglu, M. . . . . 1478
Sae-Ung, S. . . . . 1364
Sahu, N. . . . . 1409
Salama, M. . . . . 1548
Salim, A.-H. . . . . 1480
Salmonte, A.J. . . . . 1496
Sandler, I.S. . . . . 1551
Sandström, S. . . . . 1408
Sato, T.B. . . . . 1382
Savkar, S.D. . . . . 1421
Scavuzzo, R.J. . . . . 1375
Schlinker, R.H. . . . . 1387
Schomer, P.D. . . . . 1404
Schoutens, J.E. . . . . 1538
Schwirian, R.E. . . . . 1560
Schultz, T.J. . . . . 1360
Seed, H.B. . . . . 1567
Sharbhag, R.L. . . . . 1444
Shang, E.-C. . . . . 1488
Shave, D.F. . . . . 1422
Shepherd, W.T. . . . . 1405
Shimogo, T. . . . . 1342
Shiu, K.N. . . . . 1477
Shiu, K.N. . . . . 1479
Sigillito, V.G. . . . . 1451
Simiu, E. . . . . 1366
Simko, R.J. . . . . 1531
Simonis, J.C. . . . . 1466
Singer, J. . . . . 1458
Sliwinski, A. . . . . 1532
Smith, P.D. . . . . 1373
Snow, W.L. . . . . 1541
Sobieszczanski-Sobieski, J. . . . 1391
Soda, N. . . . . 1515
Soovere, J. . . . . 1398
Striz, A.G. . . . . 1499, 1501
Sugiura, I. . . . . 1412
Suh, C-M. . . . . 1527
Sulkowski, W.J. . . . . 1403
Suzuki, H. . . . . 1340
Suzuki, M. . . . . 1472
Swanger, H.J. . . . . 1486
Swanson, C. . . . . 1383
Taflove, A. . . . . 1552
Tagart, S.W. . . . . 1377
Takagi, Y. . . . . 1529
Takahara, S. . . . . 1468
Takahashi, S. . . . . 1527
Tanaka, H. . . . . 1468
Tanaka, K. . . . . 1516, 1524
Tanaka, M. . . . . 1419
Tassoulas, J.L. . . . . 1554
Thomas, D.L. . . . . 1435
Thomas, T.J. . . . . 1385
Tichy, J.A. . . . . 1414
Tischler, M.B. . . . . 1394
Tomar, J.S. . . . . 1447
Torres, M.R. . . . . 1378
Triantafyllou, M.S. . . . . 1430
Trubert, M. . . . . 1548
Tsujimoto, Y. . . . . 1347
Tsukamoto, H. . . . . 1350
Tsushima, N. . . . . 1412
Tuncel, O. . . . . 1413
Turnage, K.G. . . . . 1536
Udwadia, F.E. . . . . 1563
Umashankar, K.R. . . . . 1552
Underwood, J.H. . . . . 1437
Utku, S. . . . . 1548
Valanis, K.C. . . . . 1514
Van Duyne, D.A. . . . . 1422
van Nunen, J.W.G. . . . . 1359
Varadan, V.K. . . . . 1558
Varadan, V.V. . . . . 1558
Vaughan, N.D. . . . . 1432
Veneziano, D. . . . . 1481
von Arx, G.A. . . . . 1365
Wada, H. . . . . 1529
Walter, H. . . . . 1550
Warlick, M.V. . . . . 1352
Warren, A.H. . . . . 1475
Watawala, L. . . . . 1459
Webb, S.W. . . . . 1473
Weertman, J. . . . . 1518
Wells, W.R. . . . . 1389
White, R.N. . . . . 1442
Whittaker, W.L. . . . . 1457
Wilkinson, D.H. . . . . 1423
Wilson, P.A. . . . . 1426
Wohlrab, R. . . . . 1344
Wolf, J.A., Jr. . . . . 1384
Wolf, J.P. . . . . 1365
Wong, H.L. . . . . 1362
Woodward, K. . . . . 1361
Yamamoto, T. . . . . 1340, 1515
Yang, J.N. . . . . 1364
Yang, S.-H. . . . . 1434
Yang, T.Y. . . . . 1501
Yap, K.T. . . . . 1356
Yoshida, Y. . . . . 1347
Youroukos, E. . . . . 1395
Youroukos, E.V. . . . . 1454
Yuan, K.-Y. . . . . 1455
Zabriski, W.L. . . . . 1536
Zak, M.A. . . . . 1498
Zeid, I. . . . . 1504
Zienkiewicz, O.C. . . . . 1553
Zinn, B.T. . . . . 1535
Ziołkowski, W. . . . . 1532

# CALENDAR

## AUGUST 1982

15-19 Computer Engineering Conference and Exhibit [ASME] San Diego, CA *(ASME Hqs.)*

16-19 West Coast International Meeting [SAE] San Francisco, CA *(SAE Hqs.)*

## SEPTEMBER 1982

12-14 Petroleum Workshop and Conference [ASME] Philadelphia, PA *(ASME Hqs.)*

12-15 1982 Design Automation Conference [ASME] Washington, DC *(Prof. Kenneth M. Ragsdell, Purdue Univ., School of Mech. Engrg., West Lafayette, IN 47907 - (317) 494-8607)*

13-16 International Off-Highway Meeting & Exposition [SAE] Milwaukee, WI *(SAE Hqs.)*

## OCTOBER 1982

4-6 Convergence '82 [SAE] Dearborn, MI *(SAE Hqs.)*

4-6 Lubrication Conference [ASME] Washington, DC *(ASME Hqs.)*

4-7 Symposium on Advances and Trends in Structural and Solid Mechanics [George Washington University and NASA Langley Res. Ctr.] Washington, DC *(Prof. Ahmed K. Noor, Mail Stop 246, GWU-NASA Langley Res. Ctr., Hampton, VA 23665 - (804) 827-2897)*

5-7 Western Design Engineering Show [ASME] Anaheim, CA *(ASME Hqs.)*

12-15 Stapp Car Crash Conference [SAE] Ann Arbor, MI *(SAE Hqs.)*

17-21 Power Generation Conference [ASME] Denver, CO *(ASME Hqs.)*

25-28 Advances in Dynamic Analysis and Testing [SAE Technical Committee G-5] 1982 SAE Aerospace Congress & Exposition, Anaheim, CA *(Roy W. Mustain, Rockwell Space Systems Group, Mail St. AB97, 12214 Lakewood Blvd., Downey, CA 90421)*

25-28 1982 SAE Aerospace Congress and Exposition [SAE] Anaheim, CA *(SAE Hqs.)*

26-28 53rd Shock and Vibration Symposium [Shock and Vibration Information Center, Washington, DC] Danvers, MA *(Henry C. Pusey, Director, SVIC, Naval Res. Lab., Code 5804, Washington, DC 20375)*

## NOVEMBER 1982

8-10 Intl. Modal Analysis Conference [Union College] Orlando, FL *(Prof. Raymond Eisenstadt, Union College, Graduate and Continuing Studies, Wells House, 1 Union Ave., Schenectady, NY 12308 - (518) 370-6288)*

8-12 Acoustical Society of America, Fall Meeting [ASA] Orlando, FL *(ASA Hqs.)*

8-12 Truck Meeting & Exposition [SAE] Indianapolis, IN *(SAE Hqs.)*

14-19 American Society of Mechanical Engineers, Winter Annual Meeting [ASME] Phoenix, AZ *(ASME Hqs.)*

## DECEMBER 1982

14-16 11th Turbomachinery Symposium [Texas A&M University] Houston, TX *(Peter E. Jenkins, Turbomachinery Labs., Dept. of Mech. Engrg., Texas A&M Univ., College Station, TX 77843 - (713) 845-7417)*

## FEBRUARY 1983

28-Mar 4 SAE Congress & Exposition [SAE] Detroit, MI *(SAE Hqs.)*

## MARCH 1983

21-23 NOISE-CON 83 [Institute of Noise Control Engineering] Cambridge, MA *(NOISE-CON 83, Massachusetts Institute of Tech., Institute Information Services, 77 Massachusetts Ave., Cambridge, MA 02139 - (617) 253-1703)*

28-31 Design Engineering Conference and Show [ASME] Chicago, IL *(ASME Hqs.)*

## APRIL 1983

18-20 Materials Conference [ASME] Albany, NY *(ASME Hqs.)*

## CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, NJ 07645

AGMA: American Gear Manufacturers Association
1330 Mass Ave., N.W.
Washington, D.C.

AHS: American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, NY 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, NY 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, IL 60605

ARPA: Advanced Research Projects Agency

ASA: Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE: American Society of Civil Engineers
345 E. 45th St.
New York, NY 10017

ASME: American Society of Mechanical Engineers
345 E. 45th St.
New York, NY 10017

ASNT: American Society for Nondestructive Testing
914 Chicago Ave.
Evanston, IL 60202

ASQC: American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, WI 53203

ASTM: American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

CCCAM: Chairman, c/o Dept. ME, Univ. Toronto,
Toronto 5, Ontario, Canada

ICF: International Congress on Fracture
Tohoku Univ.
Sendai, Japan

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, NY 10017

IES: Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IFToMM: International Federation for Theory of Machines and Mechanisms
U.S. Council for TMM
c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA: Instrument Society of America
400 Stanwix St.
Pittsburgh, PA 15222

ONR: Office of Naval Research
Code 40084, Dept. Navy
Arlington, VA 22217

SAE: Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096

SEE: Society of Environmental Engineers
6 Conduit St.
London W1R 9TG, UK

SESA: Society for Experimental Stress Analysis
21 Bridge Sq.
Westport, CT 06880

SNAME: Society of Naval Architects and Marine Engineers
74 Trinity Pl.
New York, NY 10006

SPE: Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC: Shock and Vibration Information Center
Naval Research Lab., Code 5804
Washington, D.C. 20375

URSI-USNC: International Union of Radio Science - U.S. National Committee
c/o MIT Lincoln Lab.
Lexington, MA 02173



*U.S. GOVERNMENT PRINTING OFFICE: 1982 361-334/534 1-3

## PUBLICATION POLICY

Unsolicited articles are accepted for publication in the Shock and Vibration Digest. Feature articles should be tutorials and/or reviews of areas of interest to shock and vibration engineers. Literature review articles should provide a subjective critique/summary of papers, patents, proceedings, and reports of a pertinent topic in the shock and vibration field. A literature review should stress important recent technology. Only pertinent literature should be cited. Illustrations are encouraged. Detailed mathematical derivations are discouraged; rather, simple formulas representing results should be used. When complex formulas cannot be avoided, a functional form should be used so that readers will understand the interaction between parameters and variables.

Manuscripts must be typed (double-spaced) and figures attached. It is strongly recommended that line figures be rendered in ink or heavy pencil and neatly labeled. Photographs must be unscreened glossy black and white prints. The format for references shown in DIGEST articles is to be followed.

Manuscripts must begin with a brief abstract, or summary. Only material referred to in the text should be included in the list of References at the end of the article. References should be cited in text by consecutive numbers in brackets, as in the example below.

> Unfortunately, such information is often unreliable, particularly statistical data pertinent to a reliability assessment, as has been previously noted [1].
>
> Critical and certain related excitations were first applied to the problem of assessing system reliability almost a decade ago [2]. Since then, the variations that have been developed and the practical applications that have been explored [3-7] indicate that . . .

The format and style for the list of References at the end of the article are as follows:

- each citation number as it appears in text (not in alphabetical order)
- last name of author/editor followed by initials or first name
- titles of articles within quotations, titles of books underlined
- abbreviated title of journal in which article was published (see Periodicals Scanned list in January, June, and December issues)
- volume, number or issue, and pages for journals; publisher for books
- year of publication in parentheses

A sample reference list is given below.


1. Platzer, M.F., "Transonic Blade Flutter - A Survey," Shock Vib. Dig., 7 (7), pp 97-106 (July 1975).

2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., Aeroelasticity, Addision-Wesley (1955).

3. Jones, W.P., (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Devel. (1962).

4. Lin, C.C., Reissner, E., and Tsien, H., "On Two-Dimensional Nonsteady Motion of a Slender Body in a Compressible Fluid," J. Math. Phys., 27 (3), pp 220-231 (1948).

5. Landahl, M., Unsteady Transonic Flow, Pergamon Press (1961).

6. Miles, J.W., "The Compressible Flow Past an Oscillating Airfoil in a Wind Tunnel," J. Aeronaut. Sci., 23 (7), pp 671-678 (1956).

7. Lane, F., "Supersonic Flow Past an Oscillating Cascade with Supersonic Leading Edge Locus," J. Aeronaut. Sci., 24 (1), pp 65-66 (1957).


Articles for the DIGEST will be reviewed for technical content and edited for style and format. Before an article is submitted, the topic area should be cleared with the editors of the DIGEST. Literature review topics are assigned on a first come basis. Topics should be narrow and well-defined. Articles should be 1500 to 2500 words in length. For additional information on topics and editorial policies, please contact:


Milda Z. Tamulionis
Research Editor
Vibration Institute
101 W. 55th Street, Suite 206
Clarendon Hills, Illinois 60514